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ABSTRACT

The intent of this publication is to consolidate and critique research findings related to teaching and learning in the sciences as they were reported in 1990. The purposes of this and previous summaries include: (1) providing an overview of recent research activity for scholars in the field; (2) providing research information in succinct form for practitioners and development personnel; (3) stimulating ideas for further research; and (4) tracking trends in science education research. In 1990 there was increased reporting of research on conceptual change, problem solving, assessment, and women and minorities in science education. Researchers in science education appear to be using an increased variety of research methods including: standard experimental studies, ethnographies, in-depth clinical interviews, philosophical analyses, surveys, Delphi studies, and cost-effective analyses. The book is divided into the following categories: Conceptual Change and Achievement; Problem Solving; Science Process/Inquiry Skills; Cognitive Development and Logical Reasoning Skills; Assessment and Research Design; the Nature of Science; Science, Technology, and Society; Curriculum and Instructional Intervention Studies; Student Attitudes and Preferences; Equity Issues and Science Education; Students with Special Needs; Teacher Characteristics; Teacher Preparation; Policy Studies; International Science Education; Uses of Technology; Analysis of Science Textbooks; and Informal Science Centers. (More than 200 references) (PR)

A Summary of Research in Science Education 1990

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Preface

This Summary of Research in Science Education continues a long tradition of review and analysis of research in science education by the ERIC Clearinghouse for Science, Mathematics, and Environmental Education (ERIC/CSMEE). The intent is to consolidate and critique research findings related to teaching and learning in the sciences as they are reported during one-year intervals. The summaries are developed in consultation with the National Association for Research in Science Teaching (NARST). Individuals identified by the NARST Research Committee work with staff members at ERIC/CSMEE to review, evaluate, analyze, and summarize research findings. The purposes of the summaries include: (a) providing an overview of recent research activity for scholars in the field, (b) providing research information in succinct form for practitioners and development personnel, (c) stimulating ideas for future research, and (d) tracking trends in science education research.

Thanks to the authors for their efforts in producing this summary. Readers are encouraged to submit comments and suggestions after reading this summary for 1990.

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Introduction

For the 1990 review of research in science education, we have attempted to place together articles that represent major areas of interest in the field. In comparison to the 1989 review, the categories have changed relatively little, though the actual headings differ somewhat. What has changed, is the extent of interest in the various categories as indicated by the numbers of papers in each area. For example, there appears to be more interest in the research on conceptual change, problem solving, assessment, and women and minorities in science education. There also appears to be an emerging interest in the history and philosophy of science and its applications to issues in science education. Another difference (although we did not assess this formally) is that researchers in science education appear to be using a greater variety of research methods. Standard experimental studies, ethnographies, in-depth clinical interviews, philosophical analyses, surveys, Delphi studies, and cost-effectiveness analyses were among the techniques employed. In addition, the studies ranged from large scale investigations with hundreds of subjects to in-depth case studies of a few students. We see this as encouraging. As we come to understand that the problems we address are complex and multifaceted, we need to explore, develop and refine new methods of research that are appropriate for the questions

It should be noted that the categorization of the papers was not always straightforward. In making the decision regarding where each paper should be described, we attempted to locate the most central research question and use that as our guide. However, many papers addressed multiple issues, used a number of different independent and dependent variables, and could have been placed in more than one category. Perhaps this indicates that research in science education reflects the complexity of our field. In any case, readers should recognize that each paper may have something to say to issues other than the one under which it is placed.

In addition to categorizing and reviewing each paper, we also have commented on each set of papers. The comments range from statements encouraging the continuation of efforts, to criticisms, to suggestions regarding what else can or should be considered in future efforts. We hope these comments prompt discussion of our field and provide some insights into the research that was reported in 1990.

Conceptual Change and Achievement

A major area of research was related to what science students have learned from previous instruction and experience. Generally, studies support the common claim that even the best students were not being as successful at learning science as is desired (Ferko). Other, more specific studies, also indicated that the learning of science from relatively traditional methods and experience is less than optimal. A number of these studies were conducted as a part of or as a prelude to research based on theories of conceptual change.

There were 38 papers related to conceptual change or achievement. Of these 23 were journal articles, 2 were technical reports, 5 were papers presented at national meetings, and 8 were dissertation studies. These papers were divided into five relatively distinct categories. The studies dealt with questions about students' prior knowledge, understanding how conceptual change occurs, teaching strategies, concept mapping, and factors that influence student conceptions or achievement.

Students' Prior Knowledge

A primary feature of the studies related to conceptual change has been the determination of what conceptions of natural phenomena students can be expected to bring to the classroom. These studies provide researchers, curriculum developers and and science teachers insight into how well students are learning science. They also provide a basis for designing instruction that accounts for students' initial conceptions and especially their misconceptions. There were four studies in this group.

Physical Science

Duit and Kesidou investigated students' views of the second law of thermodynamics so as to find a starting point for conceptual change instruction. The 34 students in their study had been taught physics two days a week for four years in their grammar schools in Germany. The students, who had been taught the concepts of heat, temperature, energy and the particle model of matter, were given an 8-part clinical interview about such events as metal being cooled in water, metal being heated in water, two objects made of the same metal being placed in contact, or about the possibilities such as cold tea becoming hot by itself or a pendulum beginning to swing by itself when the surroundings are cooled. The students' view of the reversibility or irreversibility of events was of particular interest. The analyses of the interviews involved a complex process of interpreting and categorizing the students' responses in a way that provided a defensible description of the students' way of thinking about the interview problems and allowed for comparisons among students regarding the similarities and differences in their views. The results indicated that the students had great difficulty differentiating between heat and temperature; viewed energy as something which caused actions and effects; seldom presented ideas about energy transport, conservation, and degradation; and seldom referred to a small particle model of matter. In addition, while the students did know that the process of temperature equalization could not be spontaneously reversed or that a pendulum would start swinging by itself by cooling the air around it, they did not understand the irreversibility of the phenomena in terms of an appropriate physics framework. The authors concluded that the students do not learn the basic concepts of the second law of thermodynamics during traditional instruction and that the conceptions they did have following the instruction would not provide an fruitful starting point for additional instruction.

Renner, Abraham, Grzybowski, and Marek studied 257 seventh and eighth grade students who had studied expansion, the Dopler effect, floating and kinetic energy by using textbooks and typical teaching methods. With respect to expansion, they found that only 16% of the students had a sound understanding; 45.5 % of the students had a partial understanding without an evident misconception; and the understanding of 35.4% of the students had a specific misconception. With respect to the Dopler effect, only 2.3 % achieved a partial or sound understanding, 49.8% presented specific misconceptions and 47.9% had no understanding or could not respond to the questions at all. For floating, only 6.8% demonstrated a partial or sound understanding; 38.9% present evidence of specific misconceptions, and 44.3% showed no understanding or did not respond to the question. The results were similar for the kinetic energy question. Only 31.9% provide a sound or partial but correct conception, 42% presented specific misconceptions and 26.1 % presented no understanding or were non responders. Instruction involving the use of the textbook was not very successful. When the results were examined in terms of the level of the concept (concrete or formal) and the operational level of the students (concrete, transitional, formal), the only marginally acceptable result was that 77% of the transitional and formal operational students developed a sound or partial understanding of expansion, the one concrete concept that was considered.

Life Science

Brody and Koch investigated fourth, eighth and eleventh grade students' knowledge of marine science and natural resource issues. After a careful description of the knowledge domain of interest generated 15 key scientific principles, approximately equal numbers of students at each grade level (N = 187) were given clinical interviews regarding the geography and ocean bottom topography of the Gulf of Maine, physical and chemical oceanography, marine ecology, and marine natural resources. The students' correct concepts, misconceptions and missing concepts were tabulated based on the initial analysis of the content domain. The responses were also scored as a fully complete conception, a partially complete conception, a limited conception or a completely missing conception. The interview scores for each principle was relatively low and indicated that students at each grade level understood relatively few principles with only minor gains being made between 4th and eleventh grade. The interviews revealed a number of missing or very limited conceptions and misconceptions associated with the each principle. Key missing or limited conceptions were related to the effects of water movement on the dynamics of a marine ecosystem, photosynthesis, and energy flow in ecosystems. Among the most striking misconceptions were that students believed that coral reefs existed throughout the North Atlantic, some deep aquatic plants (seaweed) do not need sunlight, the oceans are a limitless resource, and that there are no political boundaries in the oceans. The authors concluded that students' knowledge in this domain is considerably more limited than it should be and that the results can be used as a foundation for curriculum development that will address the students' misconceptions.

In a somewhat different type of study, **Amir and Tamir** assumed that students would hold misconceptions following instruction and sought to determine precisely which misconceptions about photosynthesis students held before remedial instruction was initiated. The study included 285 students in 11th or 12th grade classes who had completed instruction about photosynthesis in Israel. A test was constructed based on known misconceptions and included multiple choice, multiple choice plus justification, open ended, and sentence forming items. Results were reported for 2 pairs of items to illustrate the approach that was taken. Only 55% answered the question on limiting factors in photosynthesis correctly when the students' responses and their justification of their choices were considered. Similarly, only 42% gave a correct response on an open ended question. A comparable result was evident with respect to the students' responses to a question about the recycling of carbon dioxide and oxygen in nature, i.e., photosynthesis and respiration. Only 43% of the students choose a correct answer and correctly justified their response. While the study was useful in that the authors were able to indicate to the teachers the misconceptions that needed addressing and make specific suggestions as to how to plan the instruction, one can be sure it was disappointing to find so many students in need of remediation closely following instruction.

Reviewer Comments

Results such as those provided above are perhaps not surprising in light of many reports over the past several years regarding the results of standard instructional practices. However, these studies provide additional insight regarding the specific subject matters students find difficult to understand and descriptions of students' knowledge that can be used to design alternative instructional approaches that may be more successful.

Understanding How Conceptual Changes Occur

Another category of studies that assist us in understanding conceptual change included six studies regarding how students' conceptions change. More specifically, each of these studies is concerned with the ways in which students' initial knowledge interacts with the instructional content.

Westbrook, Rogers, and Marek uncovered the possibility that students' ideas may occur in subtle shifts as they attempted to identify and analyze factors that influence shifts in tenth grade biology students' (n = 64) understandings of the concepts of diffusion. The effects of reasoning level, ability to utilize science process skills, gender and instructional treatment on the qualitative and quantitative nature of students' conceptual shifts were analyzed. One of the instructional treatments was text-based expository teaching, the other was teaching by the learning cycle. The students' understanding of diffusion was assessed by having them write a paragraph in which they had to explain what would happen to drops of dye placed in ten gallons of water. The students' responses were categorized as indicating a complete understanding, sound understanding, partial understanding, partial understanding with misconception, specific misunderstanding, no understanding and no response. This categorization scheme was used to track both positive and negative shifts in the students' understanding. The summary of pretest and posttest scores provided little insight into changes in the students' understanding. However, when the various shifts in students' understanding were examined a different picture emerged. Only 11% of the students maintain their initial understanding of the concept. Sixty one percent of the students increased their understanding and twenty-eight percent exhibited a negative shift in their understanding. Regression analysis indicated that treatment significantly influenced the conceptual shifts in the students understanding. The positive conceptual shift was greater for the students who completed the learning cycle instruction. Regression analysis revealed that instructional treatment and the students' ability to perform integrated science process skills accounted for a large proportion of the variance in positive conceptual shifts. This study suggests the possibility that students' knowledge "shifts", that is, changes somewhat subtly during instruction, and perhaps in ways that are not detected by pretest and posttest scores.

Similarly, **Vosniadou and Brewer** found a possible progression in the nature of students' ideas when they studied compared Greek and American children's knowledge about the shape, gravity, movement, and location of the earth and about the daylight cycle. The American subjects (n = 60) were from grades 1, 3, and 5. The Greek students were from grades K, 3, and 6. An interview questionnaire was developed to elicit knowledge students could have been taught but not integrated into their conceptual framework and the knowledge that was generative, that is , integrated into their conceptual framework for the above topics. In both samples the younger children considered the earth to be flat rather than spherical; thought that things fell downward rather than toward the center of a spherical earth; said that the earth does not move but that the sun and moon do; explained the day and night cycle on the basis of the movement of or blocking of the sun and the moon; and thought that the earth is located in the center of the solar system. The authors interpreted the changes in the students' knowledge as they became older as proceeding through three levels of understanding: (1) a level in which the students held both a superficial understanding that they had been taught and their own understanding which was used to answer an unfamiliar question; (2) a level in which they generated a misconception as they attempted unsuccessfully to reconcile their initial view with the one that had been taught; and (3) a level at which the students could use their scientific concepts in a generative way even though the initial view may still be present and used depending on the context. The authors also indicated that the differences between the groups, while great, may have been due to point at which relevant instruction began, the geographical environment, and culture-specific cosmological beliefs.

The remaining four studies considered the ways in which students' natural thinking and common sense experience interacts with instructional content. A theoretical study in this area by **Gil-Perez and Carrascosa** proposed that the recent work on conceptual change has been too closely tied to concerns about only the conceptual knowledge of students. They point out that students' initial scientific conceptions are often equivalent to the pre-classical conceptions: "the resemblance between pupils intuitive ideas and pre-classical conceptions cannot be accidental and must be the consequence of the same way of approaching problems in a very similar way which we call the 'method of superficiality.'"(p.534). They point out that this method was used by the pre-classical scientists as well as by students today and is characterized as consisting of common sense evidence, a lack of skepticism about the conclusions, no consideration of alternative possibilities, little consistency in analyzing different situations, and a lack of experimentation. Their thesis is that attempting to change students' conceptions without "simultaneously and explicitly" trying to change the students' initial "common sense methodology" will be of limited value. They propose that the students will need to learn a scientific method much as scientists had to change their methods in order to develop the scientific knowledge of today.

The Gil-Perez and Carrascosa argument is supported by a study by **Lijnse** which addresses the fundamental question of how the physicists conception of energy can "link up with the world of pupils." The author presents the view that the physics conception of energy is one which is abstract and intended to explain nature from a theoretical, uniform, coherent and internally consistent point of view and contrasted this perspective with students' situation bound, natural thinking about energy use and consumption. Lijnse presented six possible frameworks for students' conceptions of energy: Energy as (a) related to human activity levels, (b) stored in objects and causing activities, (c) something released by some activity, (d) equivalent to an activity such as motion, (e) a general kind of fuel associated with technology, (f) as a fluid. All of these frameworks were evident in the statements written by 97 students about energy. Seventy-five percent of the students wrote statements in more than one framework indicating that the students did not appear to have developed a singular, internally consistent framework. The students seemed to hold multiple views of energy related to a variety of their experiences. Students' natural thinking about energy was characterized as "strongly anthropomorphic, material (substance like) causal and non-mathematical" (p. 576). Specific difficulties were evident with students' conceptions of energy conservation. They viewed energy as something which is consumed and as a result becomes less useful or lost. The author also examined a number of publications for the general public regarding the conceptions of energy that are presented. The results indicated that the publications presented energy as "material (a fuel) which has limited availability, which is used or consumed for our benefit and is lost in that process, and which therefore must be dealt with carefully" (p. 577). Given the above contrast between students' "natural thinking" and the physicists "theoretical thinking", Lijnse proposes three levels of concept development that combines a constructivist perspective with the Science-Technology-Society approach. The first level necessitates the selection of life-world situations that are relevant to the students and yet can be considered in the context of physics lessons. The intent of this step would be to assist students in developing "pragmatic relevance," the knowledge and skills which are necessary for acting on life-world situations. At the second level life-world notions are quantified and developed so that the relevant energy situations can be described, situation specific calculations can be made, and the relative merits of "energy-saving" measure can be argued. At the third level, the students would learn to adopt the physicists' theoretical, explanatory, unifying goal by beginning with idealized situations then return to reconsider the second level of description from the perspective of physical theory.

Gussarsky and Gorodetsky described one way in which students' common sense experience merged with the instructional content. Word associations were used to map 309 grade 12, Israeli high school students' conceptions of "equilibrium" and "chemical equilibrium" before and after instruction in chemistry. The students were from one of three levels of high school chemistry courses. Group C did not study chemical equilibrium and served as a control while the other two groups studied the concept at two different levels A and B with B being the higher level. The word associations produced by the students were categorized as belonging to one of two major categories, Colloquial Language or Scientific. There were several sub-categories within each major category. The two conceptions were found to be strongly differentiated before instruction. The students of all three groups associated static, everyday, physical (macroscopic) phenomena with "equilibrium." They also associated general chemistry concepts which were not connected specifically to chemical equilibrium with the "chemical equilibrium." As result of instruction the students' understanding of the two concepts merged toward a synonymous meaning. The students produced fewer colloquial language associations and more chemical equilibrium associations for "equilibrium" and fewer general chemistry concepts and more specific chemical equilibrium concepts associated with "chemical equilibrium." The authors argue that pre-instruction misconceptions of chemical equilibrium result from static notions of equilibrium from everyday experience, the use of the term "equilibrium" to stand for chemical equilibrium in texts and other instructional practices that fail to teach the students that a mixture at chemical equilibrium is a single, dynamic and not static system. They recommend that everyday phenomena be "present and analyzed as to the common and different attributes of the concepts 'equilibrium' and 'chemical equilibrium.'"

Dreyfus, Jungwirth, and Eliovitch described three other patterns to the interaction between natural thinking and instructional content. Constructivist theories of conceptual change require that students' initial conceptions be identified and, if erroneous, confronted before more adequate conceptions can be taught. The purpose of this study was to reveal some of the difficulties encountered while trying to implement this type of instructional approach. A stratified sample of 48 grade 10 high, medium and low achievers were interviewed in small homogeneous groups of 2-4 students. The interviews were about misconceptions associated with perspiring, the cell membrane, and the transmission of hereditary traits. The objective of the interview was to identify the students' misconceptions and meaningful conflicts then to try and resolve the conflicts with the students in a way that was both meaningful to them and scientifically acceptable. Three patterns of occurrences were evident in these interviews. Each of these patterns were related to students' ability to establish meaningful conflicts. First, when students' initial misconceptions could be brought into conflict with their experience-bound common sense knowledge, meaningful conceptual conflict could be established and the students could resolve the conflicts. However, the students often went on to construct new ideas independently that were not necessarily scientifically adequate and instruction would have to be continued so that these new ideas could be considered. The second pattern occurred when the challenges to the students' initial conceptions could only be based on cultural knowledge or a model that goes beyond direct and immediate experience. In this case, it was possible to establish meaningful conflict and establish a need for a better theory. However, given the initial scientific level of the students' knowledge which was an incorrect, intuitive interpretation of what hey had been taught previously, the students were unable to construct an adequate alternative. The third pattern occurred when students' initial misconceptions (for example those about trait transmission) could not be developed from any type of daily experience. The students' initial misconceptions seemed to be their own intuitive misconceptions that reproduce theories of the 19th century. The only way to create dissatisfaction with their theories was to initiate conflict with other learned formal knowledge such as their knowledge about chromosomes or mitosis. However, even after these conflicts were established and the student learned an alternative, they did not necessarily give up their initial theory. In addition, the authors found that the better students enjoyed the conflicts and challenges, while the less able students tried to avoid the conflicts to protect their self-image. When students' initial experience based knowledge conflicted with formal, school knowledge the latter did not have much impact on the students' thinking. The students neither believed or rejected the school knowledge. They just preferred their own. In other words, "they were just indifferent" (p. 565). In short, the students' attitudes toward school knowledge were important.

Reviewer Comments

This set of studies indicates that we are beginning to understand how conceptual change occurs. This reviewer believes that more in-depth studies of how students' "common sense" knowledge changes in response to innovative arrangements of instructional content offers one promising avenue for research. If we can describe in some detail exactly what types of transformations of instructional content are made by students as their prior knowledge interacts with instructional content, then we can perhaps move forward and develop theories of conceptual change that will allow us to predict what students will know after instruction.

Teaching Strategies

There were six studies that were primarily attempts to improve upon traditional practices and change students' conceptions of natural phenomena. Broadly conceived, the instructional strategies were based on conceptual change theories and typically involved multiple steps in the instructional plan. The authors typically reported students' initial conceptions as well as the effects of the instructional design.

Physical Science

Lee, Eichinger, Anderson, Berkheimer and Blakeslee attempted to understand the conceptual frameworks students use to explain the nature and structure of matter and molecules. Twenty four students from four sixth grade classrooms were interviewed prior to instruction for each of two years. The clinical interviews required students to describe and explain: (a) the nature of matter and the states of matter, (b) expansion and compression of gases, (c) changes of state, (d) dissolving, and (e) thermal expansion at both a macroscopic and molecular level. Students' responses were judged as representing a scientific goal conception, a partial understanding of a conception, a misconception or ambiguous. The results indicated that most students had misconceptions at the macroscopic level and did little more than guess about what matter was like at the molecular level. The authors report numerous specific misconceptions associated with each of the phenomena students were asked to describe and explain. Among them is the notions that matter is anything you can feel or see. This lead to the students excluding gases as a type of matter and confounding the distinction between gases and and forms of energy such as heat and light which can be seen and felt. Other misconception were related to the conservation of matter during physical changes. At the molecular level many students had never heard of molecules and when asked to describe matter at a sub-microscopic level, many students used observable properties such as specks of dust in the air. Of those students that did have a molecular conception to draw on many had misconceptions. For example, one misconception was that molecules are *in* matter as opposed to the idea that matter is composed of molecules. As corollary to this idea, many of these students believed that the spaces between molecules were filled with "other stuff" such as air.

A second purpose of this study was to assess the effectiveness of two alternative instructional units in helping students change their initial conceptions. The two instructional modules were different in several ways. Two of the key differences were: (a) One unit (Models of Matter) consisted only of canonical scientific knowledge while the second unit (Matter and Molecules) was based on specific students' conceptions and misconceptions as well and (b) the Models of Matter unit focused only on molecular conceptions while the Matter and Molecules focused on the physical changes in matter as well and emphasized the associated molecular conceptions. The units were taught to 15 elementary school classes by 12 teachers during two successive years. Students were tested either by clinical interview ($n = 24$ each year) or by paper and pencil tests that were designed to elicit students' conceptions and misconceptions of physical changes in matter at both the macroscopic and molecular levels. The statistical analysis of class means indicated that the differences in achievement were significant for nine of ten categories of students' conceptions. The results also indicated that during the Models of Matter unit many students learned the molecular "language" while retaining many of their initial misconceptions. Overall, the students showed a scientific understanding of only 28% of the scientific goal conceptions. The second year results were considerably better although not as good as is desirable. Overall, the students who completed the Matter and Molecules unit demonstrated an understanding of 50% of the goal conceptions. In the discussion, the authors indicated that the key conception for the students to learn was that "Matter consists of tiny particles called molecules that are constantly in motion" but that there were substantial difficulties and complexities in understanding nearly every aspect of this single statement. However, they also indicate that grade six students are capable of understanding a number of the important ideas in the kinetic molecular theory and that understanding the molecular model is critical to understanding a number of other critical physical science, life science and earth science topics.

In a second, physical science study, **Tomasini, Gandolfi, and Balandi** investigated eight and nine year old children's "ways of looking" at sinking and floating. The results indicated that the children "looked at" buoyancy in terms of the the roles played by (a) material and weight, (b) shape, cavities and holes (c) air, and (d) water For example, holes in an object take material away making it lighter and allowing it to float or the holes let water into objects making them heavier and sinking them. Water, which is not seen as the medium in which objects are immersed but as something that plays different roles, goes into or stays on an object and sinks it. Students also believed that water plays the role of pushing an object up or down into the water as opposed to pushing on it from all directions. After the pretest the students were given a sequence of instructional activities. The sequence consisted of "messing about" activities designed to motivate students and have them make their initial ideas and reasons for those ideas explicit, a gradual, extended series of "intervention" activities designed to assist students in restructuring their ideas and final a set of "reflection" activities in which students reconsider what they had thought and done previously using their new way of "looking at" sinking and floating. The results of the study were reported as illustrative excerpts from transcripts from videotapes of the instruction. The students final view was, while still incomplete, considerably less animistic and egocentric and more compatible with an accepted scientific interpretation than was their initial view. The researchers concluded that the students' views had evolved in ways that were desirable. They strongly argued that a style of research which did not focus on the statistical features of a phenomenon of learning but on the dynamical ones, (such as) following the evolution of the (students') various 'ways of looking' at phenomena in real classroom setting is essential to improving educational practice.

Life Science

Bishop and Anderson assessed the prior knowledge of college students in a non-majors biology course using a written instrument designed to elicit students' conceptions of evolution by natural selection. The results revealed that students' thinking differed from accepted biological theory in that (a) changes in traits were attributed to a need-driven adaptive process rather than random genetic mutation and sexual recombination, (b) no role was assigned to variation on traits within a population or differences in reproductive success, and (c) traits were seen as gradually changing in all members of a population. They also found that students substantially confounded the everyday meanings of the terms adapt/adaptation and fitness with the scientific meaning of those terms. Subsequently, students were given instruction designed to promote conceptual change. The instruction increased the number of students who were able to use scientific conceptions to explain evolutionary changes from 25% to 50% indicating that learning these concepts is possible given instructional materials that are carefully designed to account for the students' prior knowledge but still quite difficult.

In another study of college non-science majors biology 105 students were tested to reveal their conceptions of respiration and photosynthesis before and after course instruction. The pretest asked students to define respiration, and photosynthesis, explain how plants and animals get food and to explain how they saw various biological processes and concepts as related. Clinical interviews were used to validate the tests. The results of the tests were coded in a way that provided descriptions of students conceptions and allowed for the classification of students according to their conceptions. Students were instructed after the pretests using modules designed to promote conceptual change. The pretest indicated that serious misconceptions existed prior to the course even though most students had completed at least one year of high school biology. In sharp contrast to the biological view of respiration, over 80% of the students provided definitions of respiration as synonymous with breathing. Few students mentioned food or energy. With respect to photosynthesis students responded with a variety of statements regarding what they could remember from previous instruction, but only 14% mentioned glucose or food as a product of photosynthesis and only 28% mentioned the conversion of sunlight to food energy. With respect to food only 14% of the students provided essentially correct conception of "food for a bean plant" and only 25% provided correct functional definitions of "food for a person." The students' misconceptions were indicative of fundamental misunderstandings of how matter and energy are used and transformed in living systems and the associated physical laws concepts and principles such as the conservation of matter and energy, the nature of energy and the atomic-molecular theory. The authors concluded previous instruction was not successful and did not seem to prepare the students to learn from the course. Additional, evidence indicated that while the college course did improve the students' conceptions the improvements were not as substantial as is needed and that misconceptions persisted for many students. However, the authors did note that clear conclusions regarding the effectiveness of the instruction was not possible because the modules were used in different ways by different instructors. They propose that a substantial part of the problem with students' understanding of biological processes may be that the students' knowledge of underlying physical concepts and principles is inadequate.

In another study of college non-science majors biology #96 (**Anderson, Sheldon & Dubay**, 1990), 105 students were tested to reveal their conceptions of respiration and photosynthesis before and after course instruction. The pretest asked students to define respiration, and photosynthesis, explain how plants and animals get food and to explain how they saw various biological processes and concepts as related. Clinical interviews were used to validate the tests. The results of the tests were coded in a way that provided descriptions of students conceptions and allowed for the classification of students according to their conceptions. Students were instructed after the pretests using modules designed to promote conceptual change. The pretest indicated that serious misconceptions existed prior to the course even though most students had completed at least one year of high school biology. In sharp contrast to the biological view of respiration, over 80% of the students provided definitions of respiration as synonymous with breathing. Few students mentioned food or energy. With respect to photosynthesis students responded with a variety of statements regarding what hey could remember from previous instruction, but only 14% mentioned glucose or food as a product of photosynthesis and only 28% mentioned the conversion of sunlight to food energy. With respect to food only 14% of the students provided essentially correct conception of "food for a bean plant" and only 25% provided correct functional definitions of "food for a a person." The students' misconceptions were indicative of fundamental misunderstandings of how matter and energy are used and transformed in living systems and the associated physical laws concepts and principles such as the conservation of matter and energy, the nature of energy and the atomic-molecular theory. The authors conclude previous instruction was not successful and did not seem to prepare the students to learn from the course. Additional, evidence indicated that while the college course did improve the students' conceptions the improvements were not as substantial as is needed and that misconceptions persisted for many students. However, the authors did note that clear conclusions regarding the effectiveness of the instruction was not possible because the modules were used in different ways by different instructors. They propose that a substantial part of the problem with students' understanding of biological processes may be that the students' knowledge of underlying physical concepts and principles is inadequate.

In a second life science study, **Lawson and Weser** provided instruction in biology consisting of lecture and laboratories modeled after the learning cycle in the attempt to provoke significant movement away from non-scientific to scientific beliefs. Nine hundred and fifty four non-majors in biology course were tested to determine the extent to which they held non-scientific beliefs in creationism (35%), orthogenesis (30%), the soul (30% - 60%), non - reductionism (10% - 15%), vitalism (70% -80%), teleology (25%), and nonemergentism (40% - 70%). The students' beliefs were matched against the students' reasoning level (intuitive, transitional, reflective). Less skilled reasoners were more likely to initially hold the nonscientific beliefs and were somewhat less likely to change those beliefs during instruction. Following the course, reflective students were more likely than their intuitive peers to move away from the misconceptions of orthogenesis, nonreductionism, vitalism, and teleology, but neither group moved away from from a belief in creationism, the soul and nonemergentism. Less skilled reasoners were also less likely to be strongly committed to the scientific beliefs. The course did not alter the students' belief in creationism indicating that some conceptions are especially difficult to alter because of the deep emotional commitments that are involved.

Finally, **Donn** reported an attempt to attempted to change students' approach to learning from a rote approach to a meaningful approach and correspondingly, change their conceptions, by the use of Gowin's Vee heuristic. Seven hundred fifty students in an introductory, computer tutorial, college biology course were required to use Gowin's Vee heuristic as a method of analysis in several laboratory sessions. Thirty one of the students were interviewed regarding enzyme kinematics and photosynthesis. The results were the opposite to what had been expected. There was a shift toward a more rote approach by both males and females. The interpretation was that the underlying epistemology of the discipline plus the grading and teaching practices were a more dominant influence than was the use of the Vee heuristic.

Reviewer Comments

The above studies involved carefully designed sequences of activities using a conceptual change teaching strategies, the learning cycle and Gowin's Vee heuristics intended to result in substantial changes in students scientific conceptions. Overall, the results indicated that students had made some substantial progress toward developing desirable scientific conceptions and the finding warrant continued study in this domain. However, no study reported results that were entirely satisfactory. This suggests that, as reported in subsequent sections of this review, continued efforts to understand how conceptual changes occur and what influences those changes are necessary.

Concept Mapping

In addition to conceptual change teaching strategies, the use of concept mapping was also viewed as a way of assisting students in changing their conceptions of the natural world. **Wandersee** argued that concept mapping is a powerful intellectual tool in that it is a "human exercise in knowledge construction or meaning making" (p. 927). Concept mapping has a relatively long history in science education. As reported by **Novak**, it began with Ausubel's dictum that the single most important factor in a student's learning was their prior knowledge and his initial attempts to represent students' conceptual knowledge as concept maps so that changes in knowledge could be observed and described. At present a number of developing uses for concept mapping are being studied. For example, Novak indicated that concept mapping is used in the study of affective factors as they relate to cognitive factors; and the applications of concept mapping to teacher education, instructional design and the exploration of changes in students' conceptual frameworks. In 1990 there were ten@ studies reported related specifically to the use of concept mapping to improve learning.

Physical Science

The use of concept mapping in conjunction with science instructional laboratories was investigated by **Stensvold and Wilson**. Seven intact classes of ninth grade students were randomly assigned to one of two treatments. The students in the control group completed a sequence of six chemistry laboratory activities related to chemical reactions without using concept maps. The students in the experimental group received instruction in concept mapping and were required to construct concept maps before and after a series of laboratory activities. Students were tested using a 33 item comprehension test regarding compounds, products reactants, ions, and ionic and covalent bonds. The results indicated no differences between the treatment and control groups. However, a regression analysis indicated that the number of valid map links ($r^2 = 0.19$) and links per word ($r^2 = 0.15$) were significantly related to performance on the comprehension test. The results also indicated that the students who began with relatively low scores on a vocabulary subtest of the Iowa Test of Educational Development (ITED) achieved higher scores than the control students. Conversely, the concept mapping students who scored relatively higher on the ITED achieved lower scores than the control group. The concept mapping seemed to assist the students with lesser vocabularies but hinder those students with better vocabularies. The authors explained the former effect by arguing that the concepts maps may provide ideational anchoring and practice using concept labels and the latter effect by arguing that the concept mapping may interfere with the students' customary approach to learning and comprehension.

Pankratius investigated the use of concept maps in the teaching of problem solving to physics students. He argued that the use of concept maps would help students develop the organized knowledge base that is needed to solve problems. The students (n = 87) were primarily seniors from six classes. Two classes of students served as control groups. Four classes received six week of instruction on concept mapping. Two of these sections were required to submit concept maps at the end of the unit and two were required to submit concept maps before and after instruction and encouraged to continuously modify their initial maps throughout the instruction. The achievement measure consisted of a set of items from Ontario Assessment Pool which were matched to the units objectives on the conservation of energy and momentum. The results indicated that the groups which received the concept mapping instruction scored 18% higher than those students in the control group. In addition, the achievement of the students in the experimental treatment that required the greater involvement in the concept mapping was 11% better than was the achievement for the other experimental treatment. The group required to construct concept maps only after instruction preformed 6.6% better than did the control group. The author concludes that the "time requirement to teach concept mapping is well worth the benefits in achievement and understanding" (p. 324).

Allen investigated the effects of concept mapping on meaningful learning and achievement in chemistry and how students' attitudes towards mapping affects their ability to master mapping strategies and acquire meaningful learning. The sample consisted of 53 students who were randomly assigned to receive the treatment or control instruction. The treatment group was given mapping instructions, constructed maps, and completed periodic attitudinal evaluations towards mapping for fifteen weeks. All students received similar chemistry instruction. The results indicated that concept mapping did not enhance meaningful learning or achievement in science and did not affect students' attitudes toward science or the regular classroom. Students' attitudes toward mapping had no effect on meaningful learning, achievement, or mapping performance.

Life Science

Okebukola investigated Lagos State University in Nigeria pre-degree students' performance in genetics and ecology. Students were members of a one of two groups. One group was randomly assigned to the experimental treatment taught by the investigator. The other group was assigned to the control treatment. Both experimental ($n = 63$) and control groups ($n = 75$) received instruction on genetics as the first unit then on ecology as the second unit. The experimental group was instructed on how to prepare concept maps and was required to prepare and submit concept maps for each lesson associated with the two topics. The genetics unit required 21 1-hour class periods of lecture, discussions and practicals. Comparable time was required for the ecology. The students were tested using 40 item multiple choice item tests which were designed to be at the comprehension level or above. The pretest comparisons indicated no initial differences between the groups. Posttest comparisons results substantially favored the experimental group with respect to both topics. The conclusion was that completing the concept maps required students to interrelate the multiple concepts that are involved in the two topics and thus to learn them meaningfully.

Heinze-Fry and Novak investigated student achievement and attitudes toward concept mapping and meaningful verbal learning in a college audio-tutorial biology course. Students were given handouts explaining concept mapping, made individual maps and received feedback on their maps for three instructional units. Comparisons were made between these students in the experimental group and the control group on only the third unit on transport within circulatory systems. Students in both groups were volunteers and were matched as closely as possible with respect to SAT scores and prior knowledge of transport. The students' knowledge was assessed by a multiple choice test and clinical interview given immediately after and five months after the instruction. In addition, data were collected on a Thinking-Feeling-Acting Questionnaire regarding students' attitudes toward concept mapping. The results showed no significant differences between the mapping and control groups with respect to measures of initial learning, retention, and learning efficiency for their learning of the unit on transportation. However, all differences favored the concept mappers to some extent. The results indicated that high SAT students generally benefitted most from the experience and the suggested the possibility that the lower SAT students benefit over a longer period of time. The analysis of the concept maps and the students' reports of the influence on their thinking were positive and indicated concept mapping helped the students better integrate their knowledge.

Jegede, Alaiyemola, and Okebukola attempted to determine if Nigerian students' use of concept maps as a metacognitive strategy reduced anxiety and enhanced achievement and, whether or not gender has an effect on students' anxiety toward learning biology. An experimental class ($n = 22$) was taught concept mapping over a three week period and required to construct concept maps for each lesson for the following six weeks of instruction. The control class ($n = 29$) was instructed by expository teaching methods for the same time periods. In both cases students were taught selected concepts from units on Nutrition in Green plants and Respiration in Cells. Students' anxiety was measured before and after instruction using a modified version Zucherman's Affect Adjective Checklist. Biology achievement was measured using a 50 item multiple choice test related to the the above topics that was developed from past standardized West African Examination Council assessments. The reported posttest results indicated that (a) the use of concept maps improved achievement and reduced anxiety; (b) males achieved better and were less anxious than females; (c) the use of the concept mapping improved achievement and reduced anxiety somewhat more for males than for females. The authors conclude that the use of concept maps as a metacognitive strategy was effective and worthwhile.

Cliburn tested a somewhat different use of concept maps. Instead of having students develop the maps, he used them as advanced organizers for his course and evaluated the effect on learning and retention. This was done for a unit on the skeletal system. The author presented an initial concept map of the entire unit and followed up by using five subordinate maps for the experimental. The control class received the same instruction but without the concept maps. Pretest, posttest and retention tests were given. The tests were objective format content tests. Analyses of covariance using a pretest as a covariate indicated that the experimental group was significantly better with respect to learning as indicate by the initial posttest score and retention as indicated by the delayed posttest score. A multivariate analysis of covariance using age, major field, ACT composite score, high school science background courses and the pretest score indicated a difference in retention only. The author claimed that the observations "strongly confirmed the effectiveness of concept map advanced organizers for promoting long term learning and recommended their use."

Reviewer Comments

Taken as a set, the results reported above are encouraging and support the continued use and study of concept mapping. They range from substantial differences between groups favoring those students who constructed concept maps (e.g., Okebukola) to less conclusive but, none-the-less, supporting evidence that concept mapping is valuable as an instructional tool (e.g., Heinze-Fry and Novak). Yet, the results are not entirely consistent or as substantial as might be desired (Stensvold and Wilson, Allen) and further investigation of how concept mapping can be used to generate meaningful learning is needed. One promising direction for additional research and development is offered by the availability of computer based programs that allow the formulation of multidimensional maps. One such program is SemNet™. **Fischer** describes SemNet™ as a program for semantic networking that allows the user to extend the two dimensional confines of concept mapping. The power of the computer based semantic networks is that it can include many concepts and relationships and the concepts can be represented as words, images text, and sound. The expectation is that constructing semantic networks facilitates the integration of many ideas into a single structure that can be sophisticated enough to approximate the knowledge of experts.

Another possible avenue for research is suggested by **Zoller**. He argues that there are situations in which concept mapping can become a problem rather than an aid for students. In making this case, Zoller presents several examples from chemistry which are probably "the consequence of the many existing, abstract, nonintuitive, and not directly interrelated concepts and subconcepts" (p. 1055). As an alternative to concept maps, he proposes specific instructional strategies for resolving specific problems be used in cases where non-relatedness characterizes the concepts to be taught. Research into the the effectiveness of specific strategies for specific conceptual problems may be fruitful.

Factors that Influence Students' Conceptions

In addition to the studies already cited in this section, there were six studies that provided insight into what factors influence conceptual change or more traditional assessments of achievement. These studies often included reports of students' pre-instruction conceptions or the effects of a particular approach to changing students' conceptions, but also added information relevant to our theories of conceptual change.

Stavy examined children's (ages 9-15) conceptions of changes in states of matter from liquid or solid to gas, as well as their understanding of the reversibility of this process. In that context, Stavy considered what types of students' knowledge influences their conceptions. Six groups of 20 students at each grade level from grades 4 to 9 were interviewed individually for their ability to explain how matter is conserved, identified, and how its weight changes in tasks using evaporation of acetone and sublimation of iodine in closed test tubes. The authors provided a rich, detailed description of children's conceptions of changes in the states of matter. Among the specific conceptions of matter held by the students were that: (a) Gas and liquid are not perceived initially as matter; (b) as children age, their conception of matter broadened to include first liquids then gases; (c) children conceived of matter as being made up of a material core and nonmaterial properties such as color, smell, flammability, or weight; (d) the properties can be dissociated from from the material especially when the matter undergoes a change; (e) matter exists only when there is perceptual evidence of its existence; and (f) weight is not seen as an intrinsic property of matter, but instead, weightless matter can exist, or weight can change as the state of matter changes. Based on these findings and others the authors propose that students do not always employ their logical abilities to solve problems such as conservation problems. They propose that when students confront a problem different bits of the child's knowledge (declarative, operative, and other types of knowledge) compete in such a way that the strongest knowledge as determined by experience and perceptual input overcomes all other bits of knowledge. When students' declarative knowledge or certain features of the perceptual input dominate, then the students' logical abilities may not be employed. This seem to be especially true for children under twelve years old. This implies that students' conceptions of the world change in response to a number of factors

Greene found a relationship between students' conceptions and certain basic assumptions they held about the biological world. Specifically, Greene traced the logical connections between preservice elementary education students' (N = 332) mistaken assumptions about natural selection and the specific misunderstandings they used in solving an evolutionary problem. Two student assumptions were central to the investigation: (a) A population is a collection of individuals representing a common type with variations among individuals having little importance in the change process of the population; and (b) When nature changes it is not at random, but instead is teleological, orthogenic, or Lamarkian. The author generated four specific premises regarding how the students' mistaken assumptions would be used. Those premises were tested by examining students' responses to a question regarding the evolution of bats. The question was given unannounced after two lectures introducing natural selection. Students were then categorized regarding the specific ideas they used and whether or not they used them correctly. The classification scheme provided a clear and explicit indication of the students' thinking. Only 3% of the students had a true understanding of natural selection, 43% of the students had a functional understanding of selection within a typological framework (i.e., using assumption "a"), and 17% used a Lamarkian perspective. Furthermore the statistical tests clearly indicated that there is a logic to the students' misunderstandings. For example, those students within the typological framework chose mechanisms for generating changes in populations that were consistent with their choice of a selection process. Greene concluded that students are "trying to make the idea of evolution make sense" (p. 884) and suggests that integrating related topics around basic assumptions would be a sound approach to teaching evolution.

In a related study, **Linder** focused on the conceptions of sound held by a group of physics graduates who were enrolled in a teacher education program. The research approach was phenomenography, "the study of the qualitatively different ways in which people conceptualize various aspects of reality and phenomena." This study provided a description of students' conceptualizations of sound and the how these conceptualizations were strongly mediated by microscopic and macroscopic explanatory perspectives, intuition, language, and a tendency to view much of physics as abstract applied mathematics.

In addition to several specific factors such as those above, three studies were reports of general factors that influence somewhat more traditional views of students' achievement. **Jackman, Moellenberg and Brabson** studied the influence of students' conceptual systems orientation and three instructional methods (traditional, learning cycle, and computer simulation) on spectrophotometry achievement in a freshman general chemistry laboratory course. According to conceptual systems theory each person interprets and evaluates external clues according to one of four internal systems of concepts: System 1 individuals who are highly concrete in their reasoning ability and beliefs; System 2 individuals who are strongly negative toward authority and institutions and tend to autonomous and rebellious; System 3 individuals who are more abstract and tend to need to maintain secure relationships; and F individuals who are the most abstract, flexible, open minded, and have an analytical approach to problem solving. Approximately 350 students were given the "This I believe ..." test to determine their conceptual system. The test included questions related to authority, freedom and responsibility, rules, human relations, conformity, school and learning, grading, trust, independence and theories and ideas. Students were also given pretests and posttests regarding their understanding of the basic concepts of spectrophotometry. Factorial analysis of covariance indicated: (a) the students taught via the computer simulation performed better than the students taught by the learning cycle and the traditional method while the learning cycle students did not perform differently than the traditional students; (b) the System 4 students out performed the System 1 students and the System 3 students, while the System 4 students were not different than the System 3 students; and (c) no significant conceptual system by instructional method interaction. The authors primary conclusion was that the students conceptual system influences their learning in chemistry.

Okebukola and Jegede(a) argue that students' ecoculture may modify their attainment of science concepts. The ecoculture is a complex of social (family, peer group), economic, and other, environmental, variables. The authors were interested specifically in the influence of living in an automated or manual environment (General Environment), reasoning according to empirical or magical/ superstitious patterns (Reasoning Pattern) , a goal structure preference for cooperative, competitive, or individualistic work (Goal Structure Preference), and the authoritarian or permissive homes (Nature of Home) would influence science concept attainment. The sample for the study consisted of 128 Nigerian secondary students. The students were given the Socio-Cultural Inventory Scale II to measure the above variables and the Science Concept Test of 100 items from physics, chemistry and biology. The main effects for the four variables and for all interactions were significant. The main effects were discussed. Concept attainment seemed to be better for those students who lived in automated environment, preferred an empirical reasoning style, cooperative work and were from permissive homes. The authors conclude that science educators should recognize that students' ecoculture influences concept learning and consider these factors when planning curriculum and instruction.

Gooding, Swift, Schell, Swift and McCroskery reported a description of the relationship of 38 variables to achievement in high school biology and chemistry. The researchers employed a correlated factors modeling procedure to model the students' marks on the New York State regents exams in biology and chemistry based on a large set of classroom and student variables. There were 22 biology classes of students and 22 chemistry classes involved in the study. The variables included initial preclass demographic variables, pretest (attitude and perception variables collected before the end of the first three weeks of the class, pre-discourse data from an initial classroom observation, the treatment interventions, discourse data collected from four months of observations, and posttest attitude and perception scores from the last three weeks of instruction. The interventions were the use of a Wait Timer which was device with lights that was intended to used to moderate the students and teachers wait-time or Supportive Intervention which was a form of peer teaching. Of these variables initial demographics, pretest and posttest had direct links to the regents examination in biology. In the chemistry classes only initial demographics and pre-discourse had direct links to the Regents Examination score. The authors concluded that: (a) Student achievement in both courses is primarily a function of student attitudes, previous achievement, and discourse variables established during the first month of instruction; and (b) While interventions had a slight influence on subsequent discourse and student perceptions, they did not influence achievement as defined in this study.

Reviewer Comments

These studies indicated that students' conceptual changes are influenced by a variety of student factors including (a) their basic assumptions (Greene), (b) an interaction of declarative (conceptual knowledge) with other types of knowledge (Stavy), (c) their "point of view" about explanations, be they macroscopic, microscopic, or mathematical (Linder), (d) their general conceptual system (Jackman and Brabson), (e) sociocultural factors (Okebukola and Jegede (a)), and (f) student attitudes (Gooding, Swift, Schell, Swift and McCroskery). What is clear from these studies and the others cited earlier is more than the obvious fact that multiple factors influence what students learn from instruction. We seem to be learning what factors can and should be considered and ways of studying those factors.

However, we do not yet have theoretical models and associated research methods which allow us to (a) describe the interactions of the multiple factors which influence changes in students' knowledge, (b) explain what occurs, and (c) predict with much precision what types of instructional models will be required for our students to understand the natural world. What is needed is theoretical work that provides a framework for considering the relative influences of these multiple factors and subsequent empirical research to evaluate the theoretical proposals. In order to do develop better theories we need to have much more detailed descriptions of what changes in students' conceptions occur and how the changes occur in multiple scientific domains before we can elaborate and improve our existing theories. At the same time we cannot ignore practice and wait for the ideal theory. We need to develop the best innovative instructional strategies that our present theoretical and empirical research allows us and we need to test their value for students immediately. Each test of an innovative instructional strategy with students in their classrooms provides a context in which both needs can be met.

Additional Studies

Five additional studies related to conceptual change and 1 additional study related to achievement also were reported. **Klokaew** identified and compared the misconceptions about covalent bonding and structure between College of Education and College of Science students in Thailand. **C. Kim** identified and described students' intuitive ideas about water in the atmosphere and the patterns of change in students' ideas across grade and ability levels. **Eijkelhof, Klaasen, Lijnse, and Scholte** conducted a Delphi study to determine experts views of a lay persons ideas about ionizing radiation. **Engstrom** studied the use of concept maps to study the effects of kinetic structure on cognitive structure and **Lott** designed and applied a data collection system and analysis procedure that allows researchers to explore the dynamics of conceptual change as related to instructional events. **Al-Shahrani** studied predictors of students' achievement in biology in Saudi Arabia.

Problem Solving

In recent years there has been a growing interest in and concern for improving the scientific problem-solving performance of students. In 1990 there were 15 studies that focused on problem solving. Of these, nine were articles in refereed journals and six were dissertation studies. Three broad areas of problem-solving research were investigated: three studies dealt with the relationship between conceptual understanding of molecular structure and college students' numerical problem solving ability; three studies reported students' problem solving strategies; and nine papers reported investigations of various instructional strategies designed to improve students' problem solving performance.

Conceptual Understanding and Problem Solving in Chemistry

An unquestioned axiom of chemistry teaching for the last 30 years is that the ability to solve numerical problems implies an understanding of the molecular concepts behind the problem. Recent research, however, has indicated that the ability to solve numerical problems does not guarantee conceptual understanding of the molecular basis of the problem. Three studies added to our knowledge in this area. **Sawrey** investigated success on conceptual and numerical problems for the top and bottom third of class of 285 college freshman to see if the effect disappears for the high achievers. A numerical and conceptual gas law problem was included on the first exam, and a numerical and conceptual stoichiometry problem was included on the second exam. In both cases the test consisted of multiple choice questions, and the traditional numerical problem appeared immediately before the conceptual question. Students had a significantly higher success rate on the numerical problems (88% for the gas law and 66% for the stoichiometry problem) than on the conceptual problems (31% for the gas law and 14% for the stoichiometry problem). This effect did not disappear for the upper 27% of the students. These high ability students also had a significantly higher success rate on the numerical problems (96% for the gas law and 91% for the stoichiometry problem) than on the conceptual problems (44% for the gas law and 21% for the stoichiometry problem).

Pickering used the numerical and conceptual gas law problems to investigate whether the ability to do the conceptual problems is due to some special ability or due to specific knowledge. If the ability to do conceptual problems is due to a special ability, then students who successfully solve conceptual problems in freshman chemistry should perform better than unsuccessful students in the sophomore organic chemistry course. One-hundred-one students in the freshman chemistry course at Princeton were given the numerical and conceptual gas problems as part of the first test in the second semester. Of the students who enrolled in organic chemistry the following year, each student who was successful on both gas problems ($n = 20$) was paired with one whose freshman chemistry grade was as similar as possible, but who had not solved the conceptual question correctly. There were no significant differences in these two groups on their organic final examination scores or final grades in the organic course. This result indicates that the difficulty with the conceptual problem is the lack of specific factual knowledge about gases, not some ... ne ability difference. This conclusion is supported by the fact that students at three different institutions (a small rural college, a large state university, and an ivy-league college) had the same success rate on the conceptual gas law problem, but different success rates on the numerical problem, indicating differences in mathematical aptitude of students attending the three institutions.

Lythcott conducted a case study of students in two high school classes. One class received four days of instruction for solving simple mass-mass stoichiometric problems using a prescribed algorithm. The second class was taught to solve these problems using a "learning strategy" which comprised (a) a qualitative redescription of the problem, (b) estimating the mass of the product based on the balanced equation, and (c) using general heuristics (e.g., working backwards, means-end analysis) on the redescribed problem statement to get an answer. The first two days were spent analyzing one problem, so many fewer problems were solved during the four days of instruction than in the other class. After instruction, all students were interviewed. First, they solved two simple mass-mass problems out loud, while being tape recorded. Then they completed a 50 minute interview centered around four tasks designed to elicit their knowledge of the chemistry needed to solve the problems. Results are presented for the 8 students from the prescribed algorithm class and five students from the learning strategy class who solved both mass-mass problems correctly. Only two of these 13 students had a clear understanding of the proportionality of the coefficients in a balanced equation, only five expressed complete confidence in the existence of particles of water, only five were able to represent adequately the balanced chemical equation by drawing models of atoms, and only six described a mole in chemically acceptable terms. Most of the students, especially those in the prescribed algorithm group, produced correct solutions to the numerical problems, but with inadequate chemistry knowledge.

Reviewer Comments

The authors of these studies noted that these results challenge current chemistry teaching practices. More research needs to be done to determine instructional strategies that will result in both adequate conceptual understanding of molecular concepts as well as numerical problem solving strategies.

Students' Problem-Solving Strategies

Expert-novice research in chemistry and physics indicate that successful problem solvers use a series of different representations of the problem to help them solve the problem. A representation is a construction of a situation that someone uses while solving problems—a dynamic collection of structures and processes that reflects the problem solver's understanding of the task and allows the problem solver to construct a solution and communicate it to others. The purpose of the study by **Bowen** was to determine the types of problem representations graduate students construct while solving problems in organic synthesis and how they use these representations. Ten graduate students in an organic synthesis class were interviewed while solving four synthesis problems. All of the students used verbal representations, primarily for recall of specific names, structures, reactions, and grouping reactions by verbal labels. Pictorial representations were used by all students to restate the problem and generate analogies. Methodological representations (specific reaction types and sequences, such as Robinson annulation, Diels-Alder approach) were used frequently (53%) to solve for subgoals of the task. Physical and chemical principles provided another representation system useful to predict the product of a reaction, particularly when the reaction could lead to ambiguous results. The literature of organic chemistry was a representational system occasionally used (5%) to verify a step in the solution. Laboratory knowledge about reactants, solvents, physical and chemical separation, and reaction conditions formed another representational framework occasionally used (7%) for solving problems. Finally, economics (time or cost of procedure) was a representational system occasionally used (1%) to evaluate a solution.

Slack and Stewart investigated students' problem solving performance on realistic genetics problems. The subjects were 30 students from five high schools, grades 9-12, who had completed three to four weeks of genetics instruction in introductory level biology courses. The students solved 119 problems generated by the computer program *Genetics Construction Kit* (GCK). Each problem begins with a population of field-collected organisms, with the sex and phenotype of each individual identified. Students can produce offspring data by selecting individuals to be the parents for crosses. To obtain a solution, students must plan experiments, make crosses to generate data, and interpret the data by reasoning from effects (phenotypic data) to causes (genotypic data). Subjects were audiotaped while thinking out loud as they solved the problems, and a computer program recorded the initial data and the sequence of crosses performed. Three trends were observed in the general problem solving procedures of students: (a) an unplanned approach, characterized by a lack of specific hypothesis generation and testing; (b) working backwards—explaining cross data rather than predicting it; (c) emphasis on a quantitative level of counting numbers of individuals and using ratios in individual crosses. In addition, the results indicated that students lacked three important genetic-specific ways of thinking about problem solving: genotypic thinking, generational thinking, and ability to distinguish between an inheritance pattern and a modifier. Based on these results, the authors made specific recommendations for the design of genetics instruction.

Atwater and Alick investigated the level of cognitive development of Afro-American students enrolled in general chemistry courses at historically Black colleges and the strategies used by successful and unsuccessful students in solving specific types of stoichiometric problems. 30 students were randomly selected from 165 volunteers enrolled in three colleges. They were administered the 51-item Piagetian Logical Operations Test (PLOT) and interviewed while solving six stoichiometric problems: simple mole-mole, weight-weight, complex mole-mole, mole-volume, balancing a simple chemical equation by inspection, balancing a complex equation by inspection. The student's solution strategy was categorized as algorithmic or algorithmic/reasoning (uses algorithm plus inductive or deductive reasoning) on the first four problems, and as random or systematic trial-and-error on the balancing equations problems. Thirty percent of the students were classified as concrete operational, 40% as transitional, and 30% as formal operational. There was no significant correlation between students' cognitive development and the strategies they used to solve the stoichiometric problems.

There was no significant correlation between success and strategies used in solving simple mole-mole, complex mole-mole, and weight-weight problems. However, students using the algorithmic/reasoning strategy were more successful at solving mole-volume problems than those who chose a strictly algorithmic strategy. Students using a systematic trial-and-error strategy were more successful balancing simple and complex chemical equations than those using a random trial-and-error strategy.

Reviewer Comments

The rationale of these studies was that effective instructional strategies should be based on research about the common strategies and errors of students. The authors suggested that further systematic investigations are needed that connect research on students' problem-solving strategies with specific instructional techniques that help students overcome or compensate for the difficulties they encounter solving problems. For example, can students be taught systematic strategies or ways of thinking that improve their genetics and chemistry problem solving performance? Can formal instruction centered around representational systems improve students performance on complex organic synthesis problems?

Instructional Techniques to Improve Problem Solving

A wide range of instructional strategies were investigated, including the use of analogs, the use of graphic advance organizers, requiring students to formally define problem data, cooperative group strategies, the infusion of thinking skills instruction into day-to-day instruction, and the use of representational aids to improve knowledge organization and integration. The results of these studies are described below.

Two studies investigated the use of analogs to improve students problem solving performance on traditional chemistry problems. **Friedel, Gabel, and Samuel** studied the effect of using an apple-bag analog for particles-moles. The subjects were 137 students in four college preparatory chemistry classes for students who have deficiencies in their mathematical or chemistry background skills. Students in the experimental group were instructed using the factor-label method in conjunction with the use of analogies for two weeks during lectures when they were introduced to stoichiometry. Students in the control group received the normal instruction in the use of the factor-label method to solve problems. The control group solved additional problems during the two weeks. Both groups were administered three aptitude measures (the Mathematics Anxiety Rating Scale (MARS), the Modified Staver Proportional Reasoning Test (PPRT), and the rotations portion (ROT) of the Purdue Spatial Visualization Test within the first two weeks of the semester. The teacher-developed final exam consisted of 100 multiple-choice items. The treatment group that used analogs in the study of stoichiometry did not perform significantly better on the final than students in the control group who solved additional problems. The three aptitude measures accounted for 32% of the variance in final exam scores. One reason why students may not have benefited from the analog instruction may have been because they didn't see the relationship between the chemistry problems and their analogs. To test this hypothesis, a Matching Test was administered to one control class ($n = 37$) and one experimental class ($n = 38$). The

Matching Test consisted of seven analog problems that students were asked to match with seven chemistry problems. Although the experimental group performed better on the majority of the items, the percentage of items correctly matched was only about 50%. Further analysis showed that students were unable to match problems requiring the same arithmetic operations, and had difficulty distinguishing between collections of particles representing an amount (bags and moles) and numbers of particles (apples and atoms).

A second study by **Morris** obtained similar results. This study investigated the effects of gender, cognitive reasoning ability and analog-based instruction on high school students' performance on molarity problems. The subjects were 93 high school chemistry students. The treatment group received 10 days of analog-based instruction on the topics of solution and molarity. There was no mention of the analogy in the control group. Both groups were tested on molarity problems at the end of the treatment period. There was no significant treatment or gender effects. Transitional/formal students performed significantly better than concrete students regardless of the instructional strategy used to teach the molarity concept.

Mize investigated the effect of a graphic advance organizer on high school students' learning and retention of mole concepts and problems. First year chemistry classes in a Mississippi high school were randomly assigned to control and experimental groups. A twenty-five item multiple choice test was administered to all subjects as a pretest, post-test, and three-week delayed post-test. The treatment group that received advance graphic organizers while learning the mole concept did not perform significantly better on the post-test or delayed post-test than the control group.

Slick evaluated the effectiveness of a mathematical chemistry problem solving strategy that required high school students to formally define given and desired data (i.e., quantity, unit, and type of mixture or substance) in formula weight, mole conversion, molarity, and dilution problems. The content, practice problems, and feedback were provided by microcomputer programs during weekly laboratory periods for five weeks. The subjects were 46 academic-track chemistry students in a small town high school in Eastern Pennsylvania. The 22 randomly assigned students in the experimental group were required to formally define problem data, while the 24 randomly-assigned control group students were not required to show the same formality. Investigator-prepared problem solving test and attitude survey were administered before and after the treatment. Although both treatment groups demonstrated significant gains, there were no significant differences in problem solving performance of the two treatment groups. The experimental group showed a significant gain in attitude about chemistry, while the control group showed a significant gain in attitude about computers. The author concluded that further research needs to use larger sample sizes, more diverse socioeconomic students, and more complex mathematical chemistry problems.

There were two investigations of cooperative grouping strategies. The purpose of a study by **Tingle and Good** was to investigate the effect that cooperative groups, heterogeneously based on proportional reasoning ability, have on the stoichiometric problem solving of high school chemistry students. The sample consisted of 178 students in grades 10-12 from three rural, southern high schools. All subjects were given the Test of Logical Thinking (TOLT), and the two proportional reasoning items were used as a basis for forming heterogeneous groups of three or four students in classes that were randomly assigned to the experimental treatment. The subjects in the other control classes solved problems on an individual basis. Both experimental and control students were taught a problem-solving strategy based on the expert/novice research: a statement of the problem, a redescription that includes extraction of the stated as well as the implied information and a picture description, a prediction, a mathematical solution, and a check. Students were administered a pretest and posttest which consisted of multiple choice and written problems scored as right or wrong. After seven weeks, an analysis of covariance revealed no significant difference in post-test means between students of varying initial proportional reasoning skills who had been solving problems in groups or individually. Videotape analyses, classroom observations, and an examination of written work indicated that successful problem solvers, both individually and in groups, were characterized by confidence and persistence and exhibited a strong conceptual base.

Lundeberg investigated the effects of peer-led cooperative group learning program designed to encourage students to develop conceptual understanding and problem-solving ability in chemistry by articulating both understandings and misconceptions in a think-aloud fashion. The sample consisted of 108 women who volunteered to participate in the supplemental instruction and 45 women who did not participate over a two-year period. All subjects were enrolled in a two-semester college course sequence of chemistry for allied health professionals. The supplemental instruction was offered three hours weekly outside of class and lab time. The role of the leaders was to model the thinking involved in learning chemistry; listen to students' questions, comments, concerns, and answers; ask relevant questions; and to encourage students to work cooperatively in solving chemistry problems. Effectiveness of the program was measured by final grades in chemistry and responses to a questionnaire. Students who attended the supplemental instruction achieved a higher percentage of "A"s and "B"s and a lower percentage of "D"s than did the nonparticipants, and the questionnaires indicated that participants found the sessions useful and practical. The author concluded that further research is needed to determine in-depth effects of the supplemental instruction on students' learning, problem-solving, and self-esteem.

Amuah examined the effect of teaching high school physics teachers ($N = 4$) to improve thinking among their students through physics instruction. Teachers in experimental classes received training (three 1.5-hour sessions) on how to infuse and teach thinking skills in their day-to-day physics lessons. All students ($N = 168$) in both experimental classes were administered physics and thinking skills pretests, and post-tests after three months. In addition, six students from each group were interviewed to obtain protocols of students' use of thinking skills in solving physics problems. The results indicated that students in the experimental classes performed better on the physics and thinking skills post-tests than their peers in the control classes. Within experimental classes, the lower ability students benefited more from the treatment than the higher ability students.

There were two investigations of the use of representational aids to enhance students' knowledge integration or organization for problem solving. **Songer** investigated the effects of two different types of training in improving knowledge integration between typical textbook and real-world thermodynamics problems. In the first experiment, students were trained to use a concrete integration aid called the continuum line in their representation of thermodynamics problems. The continuum line helped students go beyond the surface features of the problem and simplified the discovery of commonalties between dissimilar problems, resulting in a single, integrated way to view all relevant problems. In the second experiment, students who held dissociated beliefs about real world and typical thermodynamic problem contexts were found to be less successful at knowledge integration than those who believed problems from those contexts were similar. Students received training which encouraged the belief that finding connections between the thermodynamics principles they were being taught and their natural world knowledge is an appropriate, worthwhile endeavor. Nearly all students, regardless of their initial beliefs, could be taught to integrate their knowledge. The author concluded that instructional interventions must address both students' previous conceptions about the problem domain and students' beliefs about the nature of science.

Experts in a discipline usually achieve effective recall by accommodating new materials within their existing, hierarchically organized knowledge. **Abdelhady** investigated the extent to which novices can achieve this goal when assisted by appropriate instruction. The content consisted of a complex learning task related to Cosmic Ray Physics. The subjects were 10 professors in nuclear and particle physics, who studied the learning task without instruction (experts), and 16 college non-science majors (novices). The novice students were provided with mnemonic structures characterized by strategies and representations applied directly to the learning task. Half of the subjects were administered an immediate recall achievement test, and all took a one-week delayed recall test. Experts performed significantly better than novices on both the immediate and delayed recall test. However, novices' performance on both tests ranged from 73% to 93% items answered correctly. This indicated that the novices were able to encode information in a form which enhanced the storage and retrieval of knowledge.

Reviewer Comments

Several researchers commented on the apparent ineffectiveness of the instructional strategies they investigated. Some authors suggested that for standard problems, students may come to depend on algorithms to arrive at answers in lieu of more thoughtful ways of arriving at answers. Additional research needs to be done to see if different instructional strategies could help students solve problems that are less routine in nature. In addition, the instructional time was very short in most studies. Many authors commented that future research should extend the instructional time to be sure students understand both the concepts and the strategies taught. For example, Tingle and Good commented that the students in their study had initial difficulty learning both how to interact positively with each other in groups and in internalizing the prescribed problem-solving strategy. Consequently, even seven weeks was too short a time to effect change from a memorized mode to a critical thinking mode. Future investigations need to test effects of instructional interventions by waiting until it is over, giving the controls and experimentals the same new learning experience, then testing them on the conceptual understanding and problem-solving performance of the new learning. Finally, this reviewer noted that most empirical studies measured problem-solving performance by scoring problems as right or wrong. There are many ways a student can get a problem wrong, some more serious than others. Additional research is needed to find ways of measuring students' use of an effective problem-solving strategies, regardless of whether they arrive at a correct numerical solution.

Science Process/Inquiry Skills

There were seven studies that reported the results of investigations of students' process/inquiry skills. Five were articles in refereed journals, one was a dissertation study, and one was a paper presented at a national meeting. Six of the seven studies dealt with instructional strategies to improve students' inquiry skills. Three of these studies employed an experimental-control group design, two studies used different levels of treatments and no control group, and one study used survey data to compare the inquiry skills of students' who had studied science in activity-based programs with those who had studied science from textbooks. The results of these studies are described below.

Instructional Strategies to Improve Process/Inquiry Skills

Ross(a) investigated the effectiveness of two rule-governed approaches to teaching 5th-grade children how to control variables. In the elaborative-rules treatment students were given a mnemonic to stimulate recall of the three elements of a well designed experiment: causes, effects, and controls. In the organized-rules treatment students were given a set of six rules that provided detailed direction with respect to the same three elements of an experiment. Intact classes of 5th-grade students (18 classes and 283 students) from a medium-sized school in Canada were randomly assigned to two treatments and a control condition consisting of existing teaching practices; after 4 weeks control-group classes were reassigned to the rules treatment. A controlling-variables test was given as a pretest, posttest, and retention test (3 months after instruction). Both sets of rules treatment students outperformed the traditional-instruction students (effect size = 0.75). The organized-rules method was slightly more effective overall. The elaborative-rules method had a slightly greater benefit for girls and field-dependent students.

McCune integrated Bloom's Taxonomy of Educational Objectives with the scientific method to design a new curriculum model for stimulating the critical thinking ability of 6th-grade students. 145 students enrolled in four rural elementary schools received either six weeks of this critical-thinking instruction (experimental group) or six weeks of traditional instruction of the same content (control group). Pretests and posttests were administered to measure students' critical thinking ability, achievement, and attitudes toward science. The gain in critical thinking by students in the experimental group was significantly higher than the gain of the control group. There was no significant difference in the content achievement or attitude gain scores of students in the experimental and control group.

Jones and Rowsey studied the effects of a 7th-grade unit designed to promote skills in estimating length, mass, and volume. The subjects were 242 experimental treatment students in four advanced and four average level classes, and 155 control students in three advanced- and four average-level classes in two Alabama school districts. The worksheets and activities in the five-day unit were the same for both groups, except students in the treatment group were asked to estimate a measurement before actually measuring. A 20-item estimation test was administered as a pretest, immediate posttest, and 5-week delayed retention test. Mean scores on both posttests for all groups were very low (17% - 43% correct). Although there was no significant treatment main effect for the immediate posttest, there was a significant treatment by ability level interaction: average students in the experimental group ($M = 5.02$) and control group ($M = 5.76$) scored about the same, but advanced students in the experimental group ($M = 8.54$) performed significantly better than advanced students in the control group ($M = 5.94$). On the retention test, however, the experimental treatment performed significantly better than the control treatment students, but there was no significant treatment by ability level interaction.

Berge studied the effects of group size, gender, and ability on the learning of 245 7th- and 8th-graders' science process skills using microcomputers. Twelve 7th- and 8th-grade science classrooms in three schools were randomly assigned to one of three treatments: individual students, pairs of students, and groups of four students working at microcomputers. The groups of two and four were created using random stratified sampling on ability and gender (equal numbers of boys and girls in each group). The students spent 4–5 classes completing pretests and learning how to use the computer software. They spent 5–6 days completing science lessons on weather and climate. For each lesson students first stated a purpose for an experiment, stated an hypothesis, listed variables to be controlled, and determined the information needed to test the hypothesis. They used *Appleworks* database management system and Climate and Weather Databases to arrange the relevant information, analyze the results, and draw conclusions about the hypothesis. The dependent variables were the Test of Integrated Process Skills I and II and a process skills test designed by the author to match more closely in format and style the practice students received during instruction. The split-plot, multivariate factorial analysis (two levels of gender and three levels of ability) used class means scores as raw data. The study found no significant differences between learning science process skills on a microcomputer individually, in pairs, or in groups of four. There was no significant gender difference, but there was a significant ability effect: low-ability students gained the most on the general integrated skills (TIPS) test, and high-ability students gained the most on the author-designed test.

Friedler, Nachmias and Linn investigated students learning of scientific reasoning in microcomputer-based laboratories. The subjects were 110 8th-grade students in four suburban middle schools. Two classes received 29 periods of microcomputer-based instruction emphasizing observation, while the other two were exposed to instruction emphasizing prediction. Each instructional module included: (a) off-line activities and games that introduced the concepts of observation or prediction and their role in problem solving, (b) domain-general computer games (e.g., Discover), and (c) a series of experiments investigating the heating and cooling of liquids. The students collected data using temperature probes connected to a computer that constructed an on-screen graph as the experiment progressed. Students kept lab logs which were collected and analyzed. Written tests, classroom observations, and interviews with 15 students provided additional data. Each instructional group exhibited significantly better performance over the other group in the emphasized skill. The observation group learned to make detailed observations describing the initial experimental setup, the changes that occurred during the experiment, and the results at the end of the experiment. They were able to exclude inferences from their observation logs. The prediction group students were able to make detailed predictions and justify them on the basis of their previous experimenting. However, the low percentages of students that gave correct predictions after experimenting with the same variables in five heating and three cooling experiments indicated that the students did not achieve complete mastery of this skill. There were equal gains for the two groups in both subject matter knowledge and ability to use other scientific reasoning to solve problems.

Staver and Small compared the the integrated science process skill development of three groups of 8th-graders: (a) 825 students in a suburban, middle-class Chicago school district who had studied science for several years in an activity-based program; (b) 1479 Japanese students whose science program is also activity-based; and (c) 1358 students from urban, suburban and rural North Carolina whose science programs are textbook based and reading oriented. The data from groups b and c were available from earlier research. All groups had taken the 36-item Test of Integrated Process Skills II (TIPS II). The five subscales of TIPS measure students' skill at identifying variables, identifying and stating hypotheses, defining operationally, designing investigations, and graphing and interpreting data. The American 8th-graders from an activity-based science program scored significantly higher than those from textbook-based programs on all subscales and the total score (2.5-point mean difference). The Japanese 8th-graders were significantly better than the American activity-based students in identifying variables and on the total score (2.0-point mean difference). There were no significant differences in identifying and stating hypotheses, defining operationally, designing investigations, or graphing and interpreting data.

Additional Studies

In a completely different type of study, **Jegede and Okebukola** hypothesized that a student's view or beliefs of the world (theoretical perspective) could influence the way the student observes at natural phenomena, and could determine the nature of the data collected when an experiment is progressing. To test the hypothesis, a sample of 319 Nigerian college students who had not studied biology in high school were administered two tests. The first was the Traditional Cosmology Test (TCT) designed to measure students level of belief in traditional cosmology, superstitions and taboos, and the second was a ten-item practical test requiring students to make observations of biological structures and processes. Analysis of variance results indicated that students with a level of belief in African Traditional cosmology, superstitions and taboos made significantly fewer correct observations than students with a low level of belief. There were also significant main effects for gender and religion.

Reviewer Comments

The results of these instructional studies are encouraging. They indicate that when instructional time is sufficiently long, students can make substantial gains in their inquiry/process skills by techniques which emphasize the specific skill in various ways—estimating before measuring, elaborative and organized rules for controlling variables, or a rich microcomputer-based laboratory approach emphasizing observation, prediction, or experimental design. Friedler, Nachmias, and Linn noted that students were more successful at applying the learned skil! 'o problems for which they had greater familiarity with the scientific concepts and the concepts did not conflict with their prior experience or knowledge. The study by Jegede and Okebukola supports this observation. Additional research is needed to identify the cognitive processes involved in learning scientific inquiry skills, and to apply the results of this research to the design of instruction for improving students' inquiry skills.

Cognitive Development and Logical Reasoning Skills

There were eight studies that focused specifically on students' cognitive development or logical reasoning skills. Six were articles published in refereed journals and two were dissertations. Three status studies reported the percentage of students at different grade levels with specific reasoning skills. Six studies reported investigations of the relationship between students' cognitive reasoning skills and their science achievement.

Status Studies

Jungwirth and Dreyfus determined students ability to evaluate given conclusions to both biological experiments and everyday situations. Two tests were used to distinguish among respondents who could spontaneously identify logical fallacies in conclusions and those who could identify logical fallacies in conclusions when prompted to do so. The subjects were samples of between 40 and 200 high school students, science teachers, or graduate students in Israel, West Germany, Austria, Hawaii, or the Philippines. Two tests were administered to the students. The first test consisted of 28 multiple-choice items. Half of the items included an explicitly stated, logically sound conclusion, the rest did not (students were expected to reject the given options and give a logical reason for doing so). In the first part of the second test, students were given four contextually different but logically isomorphous situations and conclusions and asked to state what they had in common. In the second part of the test, students were presented with four different but, again, logically isomorphous situations and conclusions, told that all conclusions were invalid, and asked to state why this was the case. The results indicated that only about 20% of the high school students and 40% of the teachers and graduate students spontaneously identified the logical fallacies in given conclusions. Even when prompted (by the inclusion of an explicit logically-sound option or by being told what to look for), only about 40% of high school students and 60% of teachers or graduate students recognized the logical fallacies of given situations and conclusions.

Reasoning to a contradiction is a reasoning pattern of central importance in testing alternative scientific hypotheses. **Lawson**(a) tested the hypothesis that the percentage of students who can successfully reason to a contradiction to falsify a hypothesis increases with age. The subjects were students selected from intact classrooms in grades 3, 5, 7, 9 and 11 (25 from each grade) from an one elementary, junior high, and high school located in a suburban community and 50 college students enrolled in a non-majors physical science course at a large university. The students were individually administered a four-card selection task. The subjects were given a verbal rule and four cards with pictures on them. They had to decide which cards to turn over to see if the rule was followed or not. Virtually none of the students (0% - 8%) spontaneously reasoned from a contradiction to falsify the rule. Minimal verbal instruction in the use of the reasoning pattern was then given followed by a logically analogous selection task. Performance on this task improved significantly with age from 12% among 3rd-graders to 52% success among college students. To determine if students comprehend the logic of falsification, students were shown the front and back of eight cards and asked if the card broke the stated rule. 88% - 100% of all students were able to recognize the two cards which falsified the rule, suggesting that students from grade 3 upward comprehend the logic of falsification. The author concluded that by 5th grade the necessary logical framework is in place to begin developing the reasoning skills needed to generate, compare, and test hypotheses.

In a similar study, **Piburn** investigated high school students' ability to reason about logical propositions. The subjects were 98 male and 128 female 10th-grade students in two parochial single-sex schools in Western Australia. All students were enrolled in the same General Science Curriculum. Ability to reason about propositions was measured by the 16-item Propositions Logic Test. Each item consists of a logical proposition followed by four examples, and the subject indicates which examples are consistent and inconsistent with the proposition. Four types of propositions are included. There are four conjunction propositions (e.g., It is square and it is tailed), four disjunctive propositions (e.g., It is striped or it is tailed or both), four biconditional propositions (e.g., If it is round it is small and if it is small it is round), and four implications (e.g., If it is white, then it is round). Science achievement was measured as their final grades in the course.

There were no significant gender differences on the Propositions Logic Test, but there was a significant main effect for science ability level. Mean scores were lowest for the ability to use the biconditional and implications; high-ability students correctly answered about one-third of the items, while intermediate and low-ability students were correct less than 10% of the time. Mean scores on the disjunction items were higher; high-ability students were correct on approximately three of the four items (71%), whereas intermediate and low-ability students were successful on only one-third (33% - 40%). All three ability groups were relatively successful on the conjunction items; high-ability students answered 83% of the questions correctly, while intermediate and low-ability students were successful on 70% and 76% of the items. In addition, the author found that students' grade in science correlated significantly with total score on the Propositions Logic Test ($r = 0.57$).

Reviewer Comments

The results of these studies suggest that the majority of high school students (>60%) can not reason with biconditional or implication propositions, reason to a contradiction, or identify logical fallacies in conclusions, even when prompted to do so. This result is disturbing given that the majority of scientific discourse in classrooms and textbooks takes the form of propositional statements. Both Lawson and Piburn concluded that most students would have difficulty following typical classroom or textbook discussions of the truth or falsity of hypotheses, such as the following passage from BSCS Green Version: "If there were just one gene pair in each chromosome pair, the number of traits under genetic control would be limited by the number of chromosome pairs. Some organisms would have only two or three pairs of chromosomes, and humans have only 23 pairs. Yet an organism has many inheritable traits." The authors suggested that additional research is needed in two areas: (a) preservice and inservice programs that help teachers recognize the reasoning skills of their students and target the logical complexity of their lessons in an appropriate manner, and (b) long-term instructional programs designed to improve students' logical reasoning ability.

Cognitive Development and Science Achievement

Piagetian and neo-Piagetian theories of cognitive development and their relationship to science achievement have been extensively studied in the past 20 years. In 1990, there were six studies in this area. **Cleminson**(a) investigated the match between the cognitive demands of the 9th-grade General Physical Science curriculum in Philadelphia and students' cognitive abilities. Each objective of the curriculum was assessed for cognitive demand (Piagetian level of development required for mastery) using a validated Curriculum Analysis Taxonomy. It was found that almost half of the curriculum objectives required formal reasoning for mastery. The cognitive abilities of 79 9th-grade students was assessed using two Piagetian tasks. It was found that less than 10% of these students could reason at the formal level. The author concluded that there is a mismatch between the cognitive demands of the 9th-grade Physical Science Curriculum and the cognitive abilities of students taking the course.

Berg investigated the relationship between logical thinking structures and the ability to construct and interpret graphs. Clinical interviews were used to assess six specific Piagetian mental structures as well as the graphing abilities of 72 7th-, 9th-, and 11th-grade students. The results indicated significant relationships between logical thinking and graphing abilities. Students who showed evidence of proportional reasoning did significantly better on many graphing situations. The other mental structures assessed, including Multiplicative Seriation and Euclidean and Multiplicative Measurement structures, also influenced graphing abilities. Students who did not have the logical thinking structures were more likely to be dependent on perceptual cues and less able to interpret and construct graphs correctly. For example, student difficulties with "slope versus height" were the result of incorrect interpretation of the question, lack of proportional reasoning, and additional problems in choosing the beginning and end point of the line. Difficulties in choosing the part of the graph with the greatest "rate of change" were significantly related to proportional reasoning. Locating points on a graph without a grid were significantly related to horizontal and vertical frames of reference.

The study by **Roth**(a) investigated the predictive value of five Piagetian and neo-Piagetian cognitive variables for student achievement in college science. The cognitive variables were Piagetian developmental level (eight proportional reasoning items), mental capacity (Figural Intersection Test), short-term storage space (Ratio Span Test), the cognitive style of field dependence-independence (Group Embedded Figures Test), and numerical inductive reasoning (20 items that require subjects to induce a general rule from two given pairs of numbers and then generate the missing number in the third pair). The sample consisted of a class of 32 non-science majors enrolled in Physical Science I at the University of Southern Mississippi. Since cognitive variables can affect achievement in different ways, depending upon the cognitive demands of the task, achievement in this study was analyzed for each of the categories of pure recall (14 items), computation (11 items), complex items that require processing and transformation beyond simple recall (36 items) and total score of a midterm exam, as well as the composite score on a final exam.

The correlation results indicated that developmental level (proportional reasoning) was the single best predictor of achievement, and short-term storage space was the second-best predictor. Mental Capacity and short-term storage capacity were significant predictors of achievement for computational and complex items, but, as expected from theoretical considerations, not for pure recall items. The degree of field dependence did not predict performance on pure recall or computational items. As expected, mental capacity and field dependence, two key constructs in neo-Piagetian theory, were highly correlated with each other. They did not contribute significantly to the explained variance in achievement when developmental level was held constant. Numerical inductive reasoning was a significant predictor of computational and complex items, but not for recall items. The author concluded that neo-Piagetian theories, with their focus on different aspects of short-term memory, do not completely capture the essence of formal reasoning. It is more likely that formal reasoning also relates to the efficiency and quality of problem-related schemata as well as the capacity to activate these schemata in intermediate and long term memory.

In a further analysis of his data, **Roth**(b) investigated the college students' performance on two types of physics tasks, recall items and more complex computational items, as a function of their available short-term memory space. Six pure recall items were randomly selected from the 14 questions on the midterm test. Six kinematics computational problems were selected from the 11 items on the same test to represent different degrees of difficulty as indicated by the total success rate in the class. Based on the Ratio Span Test, students were categorized into three levels of short-term storage space (STSS): 11 subjects had a ratio span of 2, 12 had a span of 3, and 9 a span of 4. There were no significant differences in performance on the recall items among the three STSS groups. There was, however, a significant difference between the STSS groups on the computational problems.

The purpose of a study by **Adey and Shayer** was to investigate whether science education in secondary schools in England could be the context in which cognitive development of average young adolescents could be accelerated. Over a period of two years, up to 30 intervention lessons were given by science teachers to their classes in eight schools, two middle schools (ages 9–14 years) and six secondary schools (ages 11 or 12 to 18 years). In addition, the project staff developed and taught the intervention lessons to two 11+ age-level classes in a secondary school designated the "laboratory" school. The 60–80 minute lessons were designed around ten Piagetian formal operational schemata: control and exclusion of variables, ratio and proportionality, equilibrium, compensation, combinatorial thinking, correlation, probability, compound variables, and conservation involving formal modeling. There was no attempt to teach rules. For each lesson, the terminology required was initially introduced in contexts which require concrete modeling only, then students were put in the position of constructing formal schema for themselves in order to solve given practical problems.

Boys who started the program at age 12+ showed a pretest-posttest effect size on Piagetian tests of 0.89 SD compared with control classes. In terms of British norms for the development of formal operational thinking, this was a mean change from 51st to 74th percentile. 12+ girls and boys who started the program at age 11+ showed no greater gain than the controls. Gains were shown by girls in one 11+ experimental class at a secondary school and in the two 11+ laboratory classes taught by the researchers. The three experimental classes that showed no effect for 11+ girls were all middle-school classes. The authors suggested that middle-school teachers lacked experience of teaching science to older students requiring the use of formal operations, and thus had more difficulty with the intervention model. If this were true, then there is some evidence that the age 11 to 13 may favor intervention for girls, whereas 12 to 14 is more favorable for boys. There was no effect on tests of science achievement during the intervention. The authors concluded that the results support using schooling to alter cognitive development, rather than merely adapting schooling to existing norms.

Reviewer Comments

In general, the results of these studies are consistent with previous research indicating that students' level of cognitive development is related to their science achievement. We are learning more about the nature of this relationship. For example, proportional reasoning skills are related to success on tasks that require the processing and transformation of information (e.g., computation, constructing and interpreting graphs), but not to simple recall tasks. Similarly, students' short-term storage space (which is correlated with proportional reasoning skill) is related to their success on computational tasks, but not to recall tasks. The results of the study by Adey and Shayer are encouraging, since they indicate that instructional strategies can be adopted by teachers that improve students' reasoning skills. The authors of the studies reviewed in this section made many of the same suggestions for future research as reported in the previous section. First, further research is needed to investigate the nature of inservice training which would enable teachers to change their teaching style in line with their students' reasoning ability. Second, additional research in instructional interventions to improve students' reasoning skills and science achievement needs to focus specifically on the transfer of reasoning skills to science achievement. Adey and Shayer suggested that the right way to test the effect of an instructional intervention is to wait until it is over, give the controls and experimentals the same fresh learning experience, and then test them on the content, concepts, and processes of the new learning.

Assessment and Research Design

There were 17 research papers that dealt with issues of assessment or research methods. Eleven were articles published in refereed journals, three were dissertations, two were papers presented at national meetings, and one was a research report. Five of the papers dealt with the development of assessment instruments and as such included determination of reliability by internal consistency and determination of validity through comparisons of scores on the new instrument with other variables. Twelve of the papers dealt with the appropriateness of specific assessment techniques. Seven of these used the critique format to discuss the techniques, five collected data which compared the use of the techniques, and one used an example to illustrate use of a technique.

Instrument Development

Enochs and Riggs and **Riggs and Enochs** discussed the development of the Teaching Efficacy Belief Instrument for elementary school teachers. Enochs and Riggs based the design of the instrument on Bandura's ideas of self-efficacy and administered it to two different samples of 331 elementary teachers and of 212 preservice elementary teachers to determine the reliability and validity of the instrument. Validity was investigated through factor analysis comparison with teacher characteristics and comparisons with scores on the subject Preference Inventory.

A dissertation study by **Kabir** also discussed instrument development, this time of an Oceanographic Knowledge Assessment Instrument. Once a reliable instrument had been designed two versions of it were constructed, one with illustrations and one without. Based on the results of an administration of the two versions to a sample of science teachers, the author decided that the illustrated version is the better format.

Smith and Welliver describe the development of a process assessment for fourth grade students. The multiple-choice test was developed to measure the skills of observing classifying, inferring, predicting, measuring, communicating, using space-time relations, defining operationally, formulating hypotheses, experimenting, recognizing variables, interpreting data, and formulating models. Items were developed by workshop participants and submitted to both the group and a panel of experts as validity checks. The first pilot instrument of 55 items was administered to 184 students. These data were used to revise the instrument to a 40-item version which was administered to 113 students. The KR-20 reliability is .80–.82, and the test-retest correlations is .77.

Taft reported a two part validation of the AP placement examination. The first part was conducted by asking 200 college and university chemistry departments to rate the relative coverage of major topics and subtopics as extensive, moderate, brief, or no coverage. The results indicated that the coverage of the major topics followed a consistent pattern but that the variation in coverage of the subtopics was substantial. The results were used to recommend that topics that were to be added and deleted from the AP examination. The results also indicated that laboratory activities were more limited in AP Chemistry than was desirable. An extended list of laboratory experiments appropriate for AP chemistry has been prepared and high schools will be encouraged to expand the amount of time allocated to laboratory activities.

The second part of the validation was conducted to establish the judge the appropriateness of a set of multiple choice examination questions for his or her class and to estimate the the percentage of students that would have been likely to answer each question correctly. A selected set of 63 colleges and universities participated in this portion of the evaluation. Eighty-two percent of the questions were judged to be appropriate by at least 85% of the respondents. The author took this distribution of judgements as evidence that no adjustment in the overall difficulty of the multiple choice items was needed.

Appropriateness of Assessment Techniques

Twelve of the papers in this set dealt with the appropriateness of assessment techniques. The paper presented by **Gong, Lahart, and Courtney** at the AERA national meeting was an extraction of survey data from existing state-wide science assessments in order to compare it to the goals set forward in Project 2061. Additional supporting information, including assessment instruments, was obtained from selected states to supplement the survey data. The investigator determined that state science assessments were not a driving force in directing either curriculum or instructional practice toward the Project 2061 goals. The state assessments were found to vary widely, the process aspects **were** weak and the content was not consistent with Project 2061 goals.

Kuechle assessed of the effects of written planning on students' ability to control variables during similar and dissimilar practical tests. The subjects were 48 randomly selected sixth grade girls and boys. The results showed that (a) students were better able to control variables on the practical tests than on the comparable written tests, (b) the girls were more likely to change their procedure after reviewing their performance on initial tests and (c) a significant correlation existed between students' understanding of the term "fair test" and their ability to write plans for controlling variables. The practical assessments were reviewed as a useful process that may assist educator's attempting to better understand students' abilities to control variables.

Lock discussed the context dependency and construct validity of practical skill assessments. Four problem-solving tasks from different contexts were administered to 18 boys and 18 girls from the fifth year of secondary school (11th grade) in England. Six boys and 6 girls were selected to be interviewed and observed. The goal of the assessment was to score the inquiry skills of observing, manipulating, planning, interpreting, reporting, and self-reliance. Pupil performance in observation and reporting skills appeared to be context dependent, while performance on interpretation and self-reliance were generalizable. The study further found that pupil performance on the practical tests correlated only weakly with external examination grades. This is interpreted to indicate that practical tests assess aspects of pupil behavior that is distinct from behavior assessed by written examinations, and that therefore, practical work should be given a prominent and discrete place in the assessment of science subjects.

Lythcott and Duschl discussed the requirements for appropriate qualitative research through the critique of a published study based on Toulmin's four pieces of an argument: the data, conclusions, warrants, and backings. They concluded, "When [the clinical interview is] used with a conscious effort toward sound argumentation, with attention to the warrants, and a directed effort to find the authority, the legitimacy in the backings for them, such data can yield defensible claims ... [otherwise it] may lead us down the proverbial primrose path" (p. 459).

O'Maoldomhnaigh and Mhaolain investigated the effect of the phrasing of a prompt on early teenage girls in Ireland. Students were asked to draw two pictures of scientists in response to two different prompts: "1. Draw a scientist" and "2. Draw a man or woman scientist." In about half the cases, the first prompt was used to elicit both drawings. In the other half,. the first prompt was used for the first drawing and the second for the second. Of 126 drawings from 68 male subjects only one was a female scientist (and that after the first prompt). Of 534 drawings from 294 girls 49% were of female scientists. The highest percentage of drawings of female scientists was obtained in the second drawings after the prompt, "Draw a man or woman scientist." **Symington and Spurling** comment on the "Draw a Scientist" test in their brief paper. They raise the point that children being asked to draw a scientist might produce the stereotypic pictures most commonly found in an attempt to make the image more recognizable rather than as a reflection of their own views of scientists. They present evidence of different types of pictures produced when children are given different prompts for the task. O'Maoldomhnaigh and Hunt reply that the scores on the test should be interpreted as reflecting possession by the subject of an image of the scientist which he or she is willing to make public.

Naik investigated the relationships among raters of student, practical science skills in South Africa. Ratings of teachers and of external moderators using and not using a marking memorandum were compared. It was determined that marking memorandums should be used and that both teachers and moderators should be given training in how to assess student performance.

Preston investigated which types of problems middle school students preferred to work on through a survey of 850 students. Students most preferred designing solutions to a problem as opposed to deciding what to do about it or finding reasons why it was a problem. No differences in preference were found for gender, race, or community type.

Sudweeks and Tolman examined test items using subjective and empirical procedures to determine which items would discriminate between male and female fifth graders. They found that the two techniques identified different items as discriminatory and, therefore, that potential bias in technique as well as in the items themselves needs to be considered.

Veldhuis investigated the use of cluster analysis in the categorization of physics problems. He provided an explicit description of the technique through an example of eight subjects classifying eight physics problems on 12 categories. He then described the use of dendograms as a statistic for comparisons between groups, such as novice and expert problem solvers.

Wallace and Mintzes investigated the validity of concept mapping as a research tool in exploring conceptual change in biology. They assigned 91 college students in an elementary science methods course to two groups. One group received 45 minutes of training on marine life zones while the other group received a placebo treatment. Both groups were asked to complete a multiple choice/free response inventory and to construct concept maps before and after the treatments. The concept maps of the subjects who had received training showed evidence of change in complexity and propositional structure, while no changes were found in the concept maps of the subjects who had received the placebo treatment. The authors conclude that concept mapping offers a valid technique for exploring conceptual change.

Willson discusses the limitations of the use of four techniques associated with expert-novice research: intact group comparisons, think-aloud procedure, retrospective studies, and naturalistic inquiries. He argued that the question of primary interest in such studies is change in novices and that the most fruitful level of change is from novice to competence. Furthermore, he argues that experimental designs are the most useful.

Reviewer Comments

Based on the research reviewed here it seems that a good deal more research is necessary in assessment. The studies reviewed here provide some new assessment devices and some comparisons of assessment techniques, but little theory is promulgated and only some practical advice can be gleaned from them. More research should be directed toward the development of theory about assessment. Additionally, research should focus on which techniques are better for which types of assessment; what are the most effective ways to use the techniques; what criteria should be used to determine effectiveness; and how do situations and assessment techniques interact.

The Nature of Science

Many individuals in science education over the years have noted that consideration of the nature of science and in fact the nature of each individual science (e.g., **Van Dyk**) is important to many aspects of science education. The development of science curricula, instructional strategies, assessment techniques and teacher education programs we develop are all influenced by our implicit and explicit views of what science is like and how it works. This means that it is essential to consider what counts as "authentic science." Seven studies were related to the nature of science. Five were journal articles and two were dissertation studies.

Martin, Kass and Brouwer noted that while there are many calls for the teaching of authentic science, there is substantial complexity involved in the determination of what counts as "authentic." They provide a description of a number of fundamental features of science that must be considered in the determination: methodology, epistemology, the scientists personal motivations, the nature of the private intellectual activity of the scientist, the translation of private science to public science, the history of science, the interactions of science and society, the interactions of technology and science, and the aims of science. In a number of these areas the authors point out that there are serious intellectual problems that have practical implications. For example, they argue that the history of science provides clear evidence that scientists do not operate according to a single method but instead have employed rich diversity of methods. They then ask how one identifies the commonalties "that both physicists and paleontologists would recognize as 'authentic science'" (p. 542). Similarly, they contrast three very different epistemological positions that have been used to describe science (presuppositionism, falsificationism, and personal hedonism) and ask how one determines which of these views or a number of other possibilities one ought to endorse as "an authentic epistemology of science" (p. 545). Given the difficulties in determining an agreed upon view of authentic science, the authors propose that we can, however, agree that any adequate view of what constitutes authentic science must at least consider each of the above key features of science. They also propose that the complexity of any view of authentic science necessitates that instead of seeking to teach an authentic view of science at a particular point in time science education ought to tend toward authenticity and draw in "as many relevant aspects of science as are appropriate at a given point in a student's life" (p. 552). They also argue that adopting this goal is consistent with the fact that students continuously construct their view of science throughout their schooling and do not formulate a single immutable view at a particular point in time. Because of this, it may be best to offer students the opportunity to learn various features of authentic science as they are appropriate at a given point in a student's life.

While the difficulties associated with determining what counts as authentic science are substantial, there are attempts to at least find the features of the nature of science about which most researchers would agree. For example, **Cleminson**(b) has carefully examined the writing of several key historians and philosophers of science and concluded that there are five features upon which there is substantial agreement. In a modified form, these key features are: (a) Scientific knowledge is tentative and should never be equated with truth; (b) Observation alone cannot give rise to scientific knowledge in a simple inductivist manner because our observations are greatly influenced by our theories; (c) New knowledge in science is produced by creative and acts of the imagination allied with the methods of scientific inquiry; (d) The acquisition of new scientific knowledge is problematic and previously held ideas are not given up easily; and (e) Scientists study a world of which they are a part, not a world from which they are separate (p. 437–438). While these statements do not address all of the aspects of science provided by Martin, Kass and Brouwer, they illustrate the type of research that is need to develop an acceptable characterization of the nature of science. As Cleminson indicates, these analyses are necessary to establish an epistemological base for curriculum reform and encouraging because the ways in which the nature of science is now being described is consistent with our emerging views of how the knowledge of an individual student changes over time.

In addition to identifying accepted features of authentic science, it is important to understand what students believe about the nature of science. This requires in-depth studies of students' beliefs about specific aspects of the nature of science. For example, **Lederman and O'Malley** investigated students' perceptions of tentativeness in science, the various sources of their beliefs, and the implications of their beliefs for personal and social decisions. Sixty-nine students from grades 9–12 were asked to complete an open ended questionnaire regarding the complex of beliefs related to the tentative nature of science at the beginning and end of the academic year. The questionnaire assessed what students believed regarding scientific knowledge as being conclusive or tentative, inductive or inventive, subjective or objective, and real or instrumental. In addition, 20 students were interviewed to validate the questionnaire, determine the sources of the students' beliefs and the implications of their beliefs for making decisions. The key findings were that students (a) neither believe scientific laws nor theories were absolute but that laws had more empirical support than theories and were more credible, (b) did not use the word proof as establishing absolute truth but instead used the word as meaning supported by evidence, (c) depended on examples as the basis of their beliefs, (d) needed an increased knowledge of the subject matter learning to understand that science was tentative, (e) did not see the laboratory as contributing to their understanding of the tentative nature of science, and (f) were relatively unwilling to make changes in their personal and social decisions without knowledge that was quite certain. The authors indicate that these findings have important implications for science curriculum and instruction. They considered the last finding especially important to note with respect to the development for Science-Society-Technology curriculum development efforts.

One example of the importance of understanding students views of the nature of science is in the teaching of evolution. **Scharmann** studied the effects of an intervention on the teaching of evolution which was based on students' misconceptions about the nature of science. Specifically, the intervention addressed the students' views that the acceptance of evolution means the rejection of religious beliefs, science is objective and independent of religious beliefs, theories are rejected if there is uncertainty on any point, and scientific knowledge is well-established and unchanging. The intervention required students to comment on and compare their feelings about evolution and creation origins, discuss their reactions in small groups, develop and present reasons for the teaching of evolution or creation origins. The group presentations were followed by an interactive lecture/discussion to resolve misconceptions that arose as part of the group work. This interaction was intended to challenge the students misconceptions with a modern view of the empirical, historical and sociological criteria of science. Finally, students indicated individually whether they had changed their views or not and why. Non-parametric comparison between a control group and an experimental group on a pretests and posttests within and between groups revealed significant differences in the students' combined understanding of the nature of science and their attitude toward evolution, but no differences with respect to their knowledge of evolutionary content. The author concluded that students benefitted substantially from the opportunity to see science, and particularly evolution, in the light of a more adequate view of the nature of science than is usually presented.

Another attempt to improve students' view of science and scientists focused on students' confusion of science and technology, the belief that science is serious and not enjoyable, and the belief that science is proven through a variety of "incomprehensible practices" (Flick(a), p. 205). The intervention was a Scientist in Residence Program (SiR) which provided students access to scientists in their classroom and a field trip.to their lab. The effects of the visit were evaluated using the Draw-A-Scientist Test before and after the SiR program. Students were also asked to write a description of what they remembered from the scientists visits. Nearly all students in control class and in the experimental class initially "drew a single, male scientist, inside, alone, working with chemical instruments" (p. 206). On the posttest, however, a number of features remained the students replaced smoking test tubes with plants and animals, showed fewer distorted faces, and changed their captions and the statements of the scientists to more positive statements about science and scientists, and represented more females as scientists. The students written responses reflected their viewing scientists more as regular people. Overall the program was effective in changing students perceptions of science and scientists. However, the authors recommended that scientists work with teacher in advance to prepare activities that will help them contend with the characteristics of young learners, especially their spontaneous thinking.

Reviewer Comments

While there were relatively few studies related to the nature of science, it seems inevitable that this area will receive greater attention in the future. The nature of science can no longer be viewed as a combination of logical procedures, routinely and dispassionately applied to objective observations. A modern view of science provides a much more complex picture of science as a dynamic human enterprise that takes place in a rich social and historical context. If this modern view is taught both explicitly and implicitly, it promises to be more interesting and valuable to students as they make the personal and social decisions that influence their lives. As the above papers indicate, we will need to research what features of the nature of science our students should learn, what their initial conceptions of science include, and to develop curriculum and instruction that is consistent with the most recent developments in our understanding of the nature of science. We also will need studies of the sources of students initial views of science and critical parts of the scientific enterprise such as explanations **(Dagher)** and studies of teacher education programs to understand how to provide teachers who can provide a different view of science than the one which they typically see during their own educations.

Science, Technology, and Society

During the past several years science educators have sought an alternative to typical practice which increasingly is seen as too narrow in perspective. **Brunkhorst and Yager** propose that a Science-Technology-Society approach provides the redefinition that is needed. They argue that "we must realize that we can no longer isolate science or any subject in the curriculum from a cultural context" (p. 62). The benefits they see in the STS approach are in relating science to real world current issues, teaching students that many critical decisions are made based on information other than ideal scientific evidence alone, the integration of knowledge, and higher order thinking skills. There is substantial interest in this position, yet for 1990 relatively little research was reported. There were four journal articles and one dissertation study, and the topics were quite disparate.

Zoller, Ebenezer, Morely, Paras, Sandberg, West and Wolthers undertook an effort to determine if the STS goals could be meet in practice. To that end they studied grade 12 students in British Columbia who had completed an STS course that had been implemented widely within the province. By implementing the course, the Curriculum Committee hoped to provide students with the opportunity to appreciate the interaction of science, society, and technology, gain knowledge of technologies as applications of science, and develop an ability to respond critically to technological issues. Among the specific subgoals were that students were to understand that (a) society controls technological development, (b) society influences and responds to scientific activity, (c) technology is a cause and result of scientific activity, (d) technology is an application of the concepts and principles of science, and (e) recognize that decisions concerning scientific and technological issues are influenced by values (p. 21). Attainment of these goals was assessed using four items taken from the VOSTS inventory. These items were given to an experimental group of 101 students who had completed the STS course the previous year and control group of 276 students who had not taken the course. The responses were used to construct an STS response profile for each group. The results indicated that the course had a substantial impact on the students' understanding of STS. More specifically, the students who had completed the course were notably better than those students who had not taken the course, especially with respect to subgoals 1 and 2 and 5 listed above.

The results of the study just cited should be viewed as encouraging for those who endorse the STS goals. Yet, the potential success of STS as a reform program may turn on a factor other than the proposed changes in curriculum and instruction. **Hart and Robottom** argued cogently that the success of the STS reform movement may depend upon the process of reform that is used to develop and implement the program. They propose that past reform efforts, such as the reform of the 1960s and 1970s, have failed because (a) the efforts have been based on a center-periphery model according to which new goals and curricula are developed by experts at the center with implementation to be carried out by teachers at the periphery and (b) the proposals from the center "did not fit (teachers') educational conditions or match their inclinations or capabilities" (p. 577).

Rhoton provide information relevant to what teachers will need to support the STS reform by investigating science teachers perceptions and attitudes regarding the implementation of STS curriculum in the Tennessee public schools. Three hundred secondary teachers were questioned regarding STS and 63% responded to the questionnaire. The teachers reported that the current science curriculum separates the learning of science from its social and technological implications and suggest that the STS emphasis should be placed in the teaching of biology, general science and earth science, and chemistry primarily at levels above the elementary school. They reported the need for inservice education programs including workshops, courses and summer internships with researchers in industry to strengthen the teachers backgrounds, the need for innovative curricular materials and a willingness to support a variety of educational changes except for the addition of a separate STS course. The results of this study are important to those considering the implementation of STS because of the obvious fact that the responsibility for the implementation will be in the hands of the teachers. Implementation efforts are quite likely to fail without understanding their perceptions of what will be necessary to successful change.

Finally, **Brunkhorst and Yager** argued that if the purported benefits of STS are to be realized, then alternative forms of assessment are necessary to the development of the approach. This argument is based on their belief that "what we assess and how we assess it determines what our curriculum looks like and the tasks we present to students in the classroom" (p.64). Given this position, the authors propose five categories of assessment as consistent with STS goals: knowing and understanding, exploring and discovering, imagining and creating, feeling and valuing, and using and applying. In addition, they describe a number of instruments that have been used as applicable to the STS approach.

Reviewer Comments

While the research on the STS curriculum reform was limited in 1990, the STS movement does require substantial attention. Perhaps the STS reform will provide a new context for the teaching of science that will be interesting and valuable for all students. Students can relate to STS issues at early ages (**Thirunarayanan**). Perhaps, studying science in the context of STS issues will improve their scientific knowledge, provide a more adequate view of the nature of science, and sustain their interest in he sciences. However, substantial research will be required. The STS reform needs to be informed by our best understanding of the nature of science, students' interests and prior knowledge, and teachers dispositions and needs. Substantial continuing evaluations of various STS development and implementation efforts will also be needed to increase our understanding of what is and is not effective.

Curriculum and Instructional Intervention Studies

The following section includes 26 studies that were conducted to examine what is or should be taught, the effects of various curriculum or instructional interventions, and associated efforts to implement curricula or instructional interventions. Of these eleven were articles published in refereed journals, and 15 were dissertation studies.

What Should be Taught

There were no studies of what should be taught in elementary schools, seven studies related to secondary schools, and one study related to college chemistry.

Secondary

Two studies were related to what is or should be taught in earth science. The earth science community is profoundly troubled by the limited extent to which the earth sciences are represented in the school curriculum and the outdated content of the curriculum that is provided. Evidence of the former problem was provided by **Winter and Yasso** who, after briefly reviewing the history of earth science education in the United States, provide data describing the earth science curricula as specified by various states. The study was made by requesting a copy of the current earth science curricula from all fifty states and U.S. territories. Thirty science coordinators responded to the initial inquiry. After the analysis of the curriculum guidelines, the analysis was returned to the coordinators to be checked for accuracy. The results of the survey indicated that only 25 states had prescribed earth science curricula and that of those only eight states provided complete guidelines; a curriculum guide, a competence list, learning objectives/goals, science teaching philosophy, and written laboratory activities. While 70% of the states covered geology, solar astronomy, and meteorology, only one state reported covering space technology, climatology, oceanography, pedagogy, cartography, environment, resources and S/T/S issues as well. The authors considered the coverage of topics to be limited in scope and were especially concerned with the absence of S/T/S issues in 65% of the state curricula and the limited the inclusion of laboratory activities in the curricula of only 12 states. They concluded that more states need to develop curriculum guidelines and resource materials for activities.

The second problem, the outdated nature of the earth science curriculum, was considered by **Mayer and Armstrong**. They reported on a conference that was intended to determine what knowledge of the earth sciences should be learned by all students before graduation. The conference was sponsored by the American Geological Institute and the National Science Teacher Association with funds provided by the National Science Teachers Association. Conference participants included approximately 20 earth scientists and approximately 20 science teachers and other science educators. The criteria that the participants were expected to apply to their deliberations were those which guided the American Association for the Advancement of Science Project 2061. The process used to conduct the conference was designed to generate a consensus among the participants. The recommendations consisted of a set of four goals. If followed, all graduates would be expected to: (a) understand the nature of scientific inquiry using the historical, descriptive and experimental processes of the earth sciences, (b) be able to describe and explain earth processes and features and anticipate changes in them, (c) respond in an informed way to environmental and resource issues, and (d) develop an aesthetic appreciation of the earth. The conference participants also developed a set of 10 concepts that were considered to be essential. The concepts were based on the premise that the earth is an interacting set of subsystems of water, land, air, ice and life. Along with the goals, the concepts are expected to serve as guidelines for the reform of earth science curriculum.

There were four studies of what should be taught in biology. **Rosenthal** examined the history of biology education to determine what can be learned regarding planning a biology curriculum for the future. The patterns she uncovered were that: (a) the goals for biology education have fallen into one of four categories, knowledge, methods, personal and social; (b) the relative emphasis placed on each of these goals has varied in response to various historical and social changes; (c) scientists, professors of education and teachers have not necessarily agreed on the relative emphasis that should be placed on these different categories; and (d) that the goal of teaching knowledge has dominated classroom practice and often been different than recommendations. In conclusion, Rosenthal argued that changes in goal categories are unlikely and that the essential challenge that must be faced is the determination of the relative importance of the goals. She also concluded that the goals need to be turned into actual classroom practices and that fundamental changes in teacher education will be needed to accomplish this change.

Two investigations considered the extent to which two of the major themes in biological education, evolution and ecology, are taught. **Shankar** conducted a study of the extent to which evolution is taught in the Texas high school biology curriculum. The rationale they gave for teaching evolution was its role as a central and unifying theme. Results were obtained from 307 teachers who represented 50% of the group that was randomly sampled. The results "indicated that the majority of biology teachers taught evolution but that they did not give it comprehensive coverage as indicated by the total time allocated to evolution and twelve topics concerned with evolution" (p. 773). Creationism was found to be taught by 28% of the teachers but as a historical or religious view because it was "fair" to do so. The coverage of creationism was not comprehensive. The survey also revealed a significant positive correlation between the emphasis placed on evolution and teachers academic background, and understanding acceptance of evolution. The teaching of evolution was negatively correlated with a conservative religious background. The author claimed that while evolution was taught it was not given the comprehensive coverage that is warranted by its status in the biological sciences.

A similar study was done in British Columbia by **Cherif** to determine the the nature of ecology in biological education. The study consisted of a literature review of the status of biological education, interviews of twenty teachers, classroom teaching observations, and analyses of textbooks and curriculum guides. The results indicated that the teaching of biology lacks a focus on ecology even though the teachers are enthusiastic and aware of its importance. The study also includes the description of a proposed ecological core content and and the social environment in which the proposed framework could be developed and implemented.

A fourth study related to curricular content was a determination of what should be emphasized in teaching people to engage in environmentally responsible behavior **(Sivek and Hungerford)**. Randomly selected samples of people from Wisconsin Trout Unlimited, Ducks Unlimited, and the Wisconsin Trappers' Association were surveyed to determine the set of variables that best predicted responsible environmental behavior. The variables considered were level of environmental sensitivity, perceived individual locus of control, perceived group locus of control, perceived knowledge of environmental action strategies, perceived skill in using environmental action strategies, beliefs about and attitudes toward pollution, technology, and psychological sex role classification. Regression analyses of the responses of the three groups indicated that the three most important predictors were perceived skill in using environmental action strategies, level of environmental sensitivity, and locus of control. The proportions of variance accounted for by the somewhat different combinations of these factors were 15% for the Trout Unlimited sample, 20% for the Ducks Unlimited sample, and 50% for the for the Trappers Association sample. The authors concluded that these three factors should be considered in the development of environmental education programs.

There also was one study related to determining what should be taught in physics. **Lijnse, Kortland, Eijkelhof, Van Genderen, and Hooymayers** described three emerging trends in physics education at the secondary school level and an effort to reform physics education which integrates the three trends. The four trends are (a) "more emphasis on the technological and societal aspects of physics, (b) a more child-oriented and activity-based classroom, (c) more attention to student relevance and (d) greater focus on the affective and social aspects of learning" (p. 95). The resulting physics curriculum is characterized by thematic units which were developed from the perspective that the physics that would be included was to be useful in everyday life, present an authentic view of physics, be interesting to students, and prepare students for future education. The structure of each unit included an orientation which established a central question, a required set of activities to stimulate independent learning in small groups, a set of optional activities which are completed by different groups of students and the reporting of their parallel activities. The parallel activities were planned so that all students contributed to answering the central question. The results are reported as a model of curriculum development that illustrates how different trends in science education can be integrated in a coherent and justifiable manner.

College

One study of what to teach was specific to a single topic in college chemistry **(Bauer)**. The purpose was to construct and validate a hierarchy of skills for the learning of concepts related to acids and bases. Fischer's Skill Theory of cognitive development was used to propose a hierarchy and construct a 27-item test in which each item corresponded to a skill on the hierarchy. The test was administered to all students enrolled in a general chemistry course at Xavier University. In addition, a random subset of students were interviewed. The proposed hierarchy was found to be invalid according to the ordering-theoretic method of hierarchy validation. Of the 54 specified relationships, ten were confirmed as proposed, twenty proposed as prerequisites were found to be independent, and six prerequisites relationships were reversed. The results were used to generate three alternate hierarchies.

Reviewer Comments

The number of studies regarding what should be taught was encouraging. Any curricular reform will require answering the basic question of what our students should learn. Without studies of both what we presently teach and deliberations about what we should teach, we run the risks of repeating past mistakes or changing what should be maintained. Furthermore, our efforts to develop effective teaching and implementation strategies will be of limited value if we have not made good decisions about what selected knowledge and skills are most important for our students. Clearly, more studies addressing this question are needed, especially at the elementary school level where the formal teaching of science begins.

Interventions

There were two elementary, six secondary studies, and two college studies of specific curricular or instructional interventions.

Elementary

One of the two studies of a specific elementary school interventions reported the effects of an elementary school astronomy curriculum that used a planetarium against one that did not use the planetarium **(Twiest)**. Researcher-developed attitude and astronomy achievement assessments were given to fourth, fifth and sixth graders ($n = 423$ in three schools) as pretests and posttests. The only significant result related to attitude favored the fourth grade control group. There were several significant differences with respect to achievement. At grades four and five the difference favored the control group with respect to knowledge-level questions. For comprehension-level questions, the control group was favored at grades four and six with the experimental group favored at grade five. Overall the results did not favor the use of the planetarium.

The other study conducted by **Brownstein** investigated the two different plans for collaboration between the New York Academy of Sciences, Teachers College, Columbia College and four New York City school districts. One plan was for the use of public science institutions, and the second was for having scientists interact in person with teachers and students. Both plans were for elementary schools and middle schools. Data was collected at monthly meetings; during interviews with district science coordinators, principals, scientists, teachers and students; on evaluation forms; and through classrooms observations. The conclusions indicated that the collaborations had positive results regarding curriculum development, improving teacher and student attitudes, and in increasing their knowledge of science.

Secondary

There were two physical science studies that tested specific curricular interventions. **Burdette** evaluated the Middle School Science and Engineering Concepts program by examining sixteen evaluative categories. The subjects were 196 students taught by nine teachers who were studied, along with the curriculum materials before, during, and after the use of the program. The project modules were judged to be meritorious and worthy of adoption. Among the specific findings were that the objectives, materials and assessment items were congruent, the program was teachable and appropriate for the students, and that scientific knowledge improved substantially.

Clayton compared the effects of providing students a mathematics unit that was related to the content of a ninth grade physical science course prior to the science unit with the effect of teaching the skills during the unit. Significant digits, scientific notation, unit analysis, equation transposing, and a structured problem solving approach were taught in the mathematics unit. Students from thirteen intact classes (N = 280) were assigned to treatment and control groups Pretests and posttests (physical science chapter tests, Piagetian tests, and science oriented mathematics diagnostic tests) were given before and after instruction. The results indicated only one significant difference. Those students who received the mathematics unit before the science instruction gained more on the science-oriented mathematics test than did the students in the control group.

Three innovations in biology were tried. One of the curricular innovations that was tested by **Hall and McCurdy** compared the inquiry oriented BSCS style biology program to a more traditional program in two small private liberal arts colleges. The comparison was made between 60 students in an experimental group who were taught the BSCS style biology and 59 students in a control group who were taught a more traditional program. The key feature of the BSCS style program was 12 laboratory activities in nine areas: (a) microscope techniques, (b) cell structure and function (c) cell transport. (d) metabolism, (e) cell reproduction, (f) genetics, (g) plant and animal diversity, (h) ecosystems and biomes, and (i) science processes. The content of the traditional sections was matched to that in the BSCS style program. The two way analysis of covariance tests using the pretests as covariates indicated a significant difference in biological science content achievement favoring the BSCS style program, and no significant differences for reasoning ability, and attitude toward biology. However, the logical abilities of both groups improved substantially. The authors concluded that educators at the post-secondary level should continue to promote BSCS style laboratory learning and attempt to promote students reasoning ability.

Phillips compared two methods of teaching high school environmental science: the traditional or textbook approach and a regionally based, hands-on activities approach developed by science teachers. Eighteen intact environmental classes in four Louisiana secondary schools were randomly assigned to the experimental (activities) and control (traditional) groups. The treatment included eight units with fourteen activities dispersed over a three month period. Students were administered a pre- and post-test consisting of 43 multiple-choice achievement questions from the Barr Environmental Inventory and 12 Likert-style attitude questions from the New Environmental Paradigm. Regression analysis indicated that the experimental group performed significantly better than the control group on the achievement and attitude portion of the posttest over and beyond any effects due to pretesting or seven demographic variables.

Baker and Piburn used teacher perception to assess the effect of a scientific literacy course. Five biology teachers were asked to compare the students they had taught during the year to students they had taught in the past that had not taken the science literacy course. The interviews with the teachers indicated that the course had an effect on the students' subsequent ability to learn biology. The teachers felt the students who had taken the literacy course were better at analyzing data, had better science process skills, and had a better understanding of the nature of science. The teachers of the advanced and intermediate biology students felt the students who had taken the literacy course were more creative, more likely to take risks and more likely to engage in hypothetical thinking.

One chemistry study by **Lehman** investigated the verbal interactions of laboratory partners in high school chemistry in order to estimate the amount of time that students spend on different types of activities. The subjects were 52 11th-grade students enrolled in two sections of chemistry taught by the same instructor. Twenty-five laboratory groups were audio-recorded over a four-month period. The groups were told to verbalize what they were doing and what they were thinking about. Tape transcriptions were used to categorize the verbal interactions, then a stopwatch was used while listening to the tapes to determine the amount of time for each verbal interaction. The results indicated that 51% of laboratory time was devoted to procedural matters, 12% to matters unrelated to the lab, 11% to data collection, 10% to the qualitative analysis of the data, and 17% to the quantitative data analysis. The fact that only about one-third of their time is devoted to data collection and analysis may partially explain why the predominance of research indicates that science laboratory activities have neither helped nor hindered students' acquisition of science concepts. The authors concluded that future research needs to be done to determine if instructional strategies that reduce the amount of time that students spend on procedural matters and increase the time spent on data analysis lead to

College

The purpose of a study by **Moradmand** was to determine if a voluntary remedial science program had an effect on student achievement, and which of several variables is a good predictor of achievement. The subjects were 194 students enrolled in an introductory biology course at a community college, 98 of whom participated in the voluntary remedial science program. The biology course is required of students entering a health field. The results of a regression analysis indicated that students who participated in the program received a significantly higher grade (by 10 points) than the nonparticipants. Similarly, the chi-square analysis indicated that more students passed the course when they participated in the program. For both groups, the ACT composite and ACT Natural Science Test scores were moderately correlated with grades, and could be considered as good predictors.

Wallace investigated the effects of an interactive theory based remedial reading course on college biology achievement. Subjects were selected from 100 college students enrolled in an introductory college biology course. The experimental treatment group of 15 students were enrolled in the interactive theory based remedial reading course that used biology reading materials to accomplish reading goals. Two control groups were selected: 15 students enrolled in a traditional remedial reading course, and 30 students who were not concurrently enrolled in a remedial reading course. Achievement in the biology course was measured by the students' average score on six biology exams. Alternate forms of the Diagnostic Reading Test were used as pre- and post-tests of reading ability. The results indicated that although the biology achievement scores of the experimental group were higher than the traditional group and lower than the non-remedial group, the differences were not statistically significant. The scores of the non-remedial group were significantly higher than the traditional group. Reading improvement scores of the experimental and non-remedial group were higher than scores of the traditional group, but the differences were not statistically significant.

Reviewer Comments

The lack of studies that were based on the application of the theories and methods from other areas of research cited in the review was somewhat disappointing. Research related to conceptual change, problem solving, the nature and history of science, and assessment do not seem to have been brought to bear in the development and investigation of curricular or instructional innovations. For example, one particular problem occurs in the light of the research on conceptual change. Without specific information regarding what changes in students knowledge occur with various innovations, it becomes difficult to know the exact nature of the effects our efforts produce. Simply knowing that intervention X was more or less effective than a control treatment no longer seems to provide sufficient information to guide curricular and instructional design.

Implementation

There were eight studies related to the implementation of various curricula or instructional innovations; all but one were about elementary schools.

Elementary

One study of elementary school implementation efforts by was by **Atwood and Howard**. They investigated the elementary teachers' perceptions of the SCIS-II program in an attempt to understand why the SCIS-II program is not more widely used given the substantial evidence that such programs are very effective. All teachers in a Kentucky school district were surveyed and the results reported are based on the return of 663 of the 685 teachers. The teachers were asked to supply information regarding teacher variables, the overall nature and operation of the program, barriers to teaching science, the effectiveness of support systems, and perceptions of student outcomes. On one hand, teachers reported their satisfaction with the program was more related to instructional concerns than logistical concerns. However, the results also showed that teachers' views of the program were related to their assessment of the barriers they faced. Teachers who rated the program more favorably perceived fewer barriers than those who rated the program less favorably. A related finding was that the primary grade teachers who evaluated the program more positively than the teachers at the other grade levels, also saw fewer barriers to its use. Specific barriers were related to the viability and care of living organisms and the design and durability of specific equipment. A second set of results related to the teachers' perceptions of the value of the program for students. Their perceptions were that the program was successful with respect to providing direct experience with science, developing social skills and positive attitudes toward science, and allowing students to experience success in school. The development of process skills, content acquisition, and the reinforcement of "basic skills" were seen to be achieved to a lesser degree. This last finding is particularly noteworthy because the teacher perceptions are contrary to the findings provided by the Shymansky, Hedges and Woodworth study. In conclusion, the authors propose that studies such as these be considered by the agencies and groups who are presently developing science curricula. Furthermore these groups should give attention to what has gone on before. continue to develop the spirit of the inquiry programs and reduce the barriers to teaching such programs.

In addition, there was a series of five studies related to the implementation of elementary school curricula reported in dissertations from the University of Southern California. These were case studies of two rural elementary schools **(Noble, Chun)**, two urban schools **(Sessarego, Swanson)**, and a suburban school **(Cole)**. These studies were from a set of seventeen case studies of schools attempting to implement new science and mathematics programs. The researchers shared the results of their literature searches, and used common research documents and methods. Data were collected by interviewing administrators and teachers, observing classrooms and reviewing documents. The reported findings were interesting because although each study provides a somewhat different insight regarding the key factors that influenced implementation, several factors were common to more than one study. Among the key factors were: (a) the use of cross-role teams of teachers and administrators, (b) a shared vision and commitment; (c) a long period of initiation and awareness development, (d) the use of state curriculum frameworks and textbook adoption process, (e) the use of mentor and lead teachers, (f) an on-going program of technical support, (g) an adequate budget, (h) administrative support for materials and supplies, and (i) a knowledgeable and supportive principal that provided leadership. As a set these studies may provide substantial insight into the factors that must be present to implement curricula effectively.

Wilson and Chalmers-Neubauer compared three elementary science programs (ESS, SCIS and SAPA) in terms of the roles played by the teachers. Teachers of the three programs, 25 each, were rated on the basis of teaching categories, and these ratings were compared within and between programs. The teacher roles varied with the manner in which hands-on materials were used in the classroom. A match was found between the range of skills needed by the teacher during hands-on instruction and the methodological orientation of the program. Necessary teachers skills could be grouped into 15 categories. The information gained in this study could be used to plan what teachers who will be implementing a new inquiry oriented program would need to know.

Secondary

Kutnick analyzed the difficulties associated with the implementation of the chemistry portion of the Nuffield curriculum which is based on a theory of cognitive development. Kutnik's primary claim was that the project encountered substantial difficulties because the developmental theory which was used to develop the program was incomplete. He argued that the theory was incomplete because intellectual development was considered to be series of changes from one stage to another without consideration of the fact tnat individuals were influenced by their social interactions. A second claim was that although the curriculum was supposed to follow developmental guidelines, there was only a limited understanding of development employed and there were "no practical insights as to how teaching may be adapted for its application" (p.89). The absence of these guidelines and the necessities of classroom management allowed the teachers few opportunities to properly match the instructional activities to the students developmental level.

Reviewer Comments

Among these studies, the ones that described the teachers' reasons for implementing or not implementing curricula were particularly interesting. If we can learn what promotes and inhibits the implementation of new curricula then we can consider those factors while developing them and plan what types of inservice may be required. Without this knowledge, we run the risk that excellent programs will not be used extensively.

Student Attitudes and Preferences

There were 20 papers that fit within this area; 3 were presented at meetings, seven were dissertations, and 10 were published in refereed journals. The studies are unique and situation specific, but some broad categorizations are possible. Six studies used measures of student attitude or preference to examine the effect of some treatment. These studies usually employed pre-post testing with questionnaires or attitude instruments. Often interactions with various student or teacher characteristics were also investigated. Four studies investigated the relationship between student attitude and behavior; three of these used regression approaches, and one was a reflective synthesis of existing information. Four studies used survey data to provide status information and regression approaches to examine student trends in taking high school classes or perceptions of reading. The remaining seven studies used survey and correlational techniques to investigate the relationships among student attitudes and other variables.

Treatment Effects on Attitude or Preference

The first broad category is those studies that use student attitude or preference, usually among other things, to examine the effect of some treatment. Six studies were grouped into this category.

Dresner examined the effect of a simulation game on players' behavior and attitudes toward energy conservation and renewable energy practices and devices. The game was constructed to serve as an approximation of an actual energy planning situation. Effectiveness of using the game was compared to a standard lecture format for 201 undergraduate students. Pre-post data were collected with a questionnaire. Participants in the game showed an increase in favorable attitudes toward home energy activism and exhibited a greater likelihood of action taking. Perceived political efficacy was seen to increase.

Fitzgerald describes a program designed to increase urban high school students' knowledge of science and mathematics as well as to promote positive attitudes toward science and mathematics course work and careers. The program is directed through a partnership of the university, the urban school districts, and local business. The students take science and mathematics courses for five weeks during the summer. In addition to the intensive hands-on course work, students visit the local industries and hear presentations by science and mathematics professionals. Pre-post comparisons on the 29 students showed gains in students interest and knowledge on investigator-prepared instruments.

Hofstein, Maoz and Rishpon investigated the effect of extracurricular science activities on attitudes toward school science of junior and senior high school students in Israel. One hundred fifty-three experimental students who had volunteered and participated in during the school-year or summer programs interacting with bench scientists were compared to 171 students not having the experience on the Attitude Towards School Science Questionnaire. Students who participated in the experience were found to have more positive attitudes in a variety of ways. Furthermore, the experimental students did not exhibit the decline in attitude from the 8th to the 11th grade which is common in the general population.

Scharf and Schibeci examined the effect of a "transition science" unit on student attitudes in senior high schools in Western Australia. Changes in attitudes of students in traditional curriculum courses were compared with students who had experienced the new curriculum. No differences were found.

Sipe investigated the effect of biology teaching strategy on student Myers-Briggs psychology type, the development of science related attitudes, and science career choices. Teacher personality types were compared with their preferred teaching strategies, and it was determined that the teachers preferred strategies corresponding to their own psychological type. Then the attitudes of 338 students of 10 exemplary and 16 randomly selected biology teachers were compared. Complex differences were found. Females of exemplary teachers scored almost as high as males of both teacher groups on enjoyment of science learning and science leisure interests. Sensing males of higher socioeconomic levels had very low attitudes on adoption of scientific attitudes, females of both teacher groups had more positive attitudes than males on normality of scientists. Students of exemplary teachers choosing biology-related careers had lower scores than students with similar career choices of randomly selected teachers. Intuitive students had more positive attitudes than sensing students on all scales.

Warren examined the effect of exposure to sex-biased collages of images of scientists on junior high school students' attitudes. The 211 students were exposed to either a male- or a female-biased collage for four weeks. Data were gathered on a questionnaire, a Draw-A-Scientist test, and a Q-sort of science occupations. It was found that student background characteristics were significant predictors of Q-sort scores, there were significant differences for treatment, and the treatment was more effective for girls than for boys.

Student Attitude/Motivation and Behavior

Six studies were categorized as investigating the relationship between student attitude or motivation and behavior. Three of the studies were based on the the theory of reasoned action. two related motivation to academic task performance and one questioned the use of attitude scales to predict behavior.

Crawley and Coe applied the theory of reasoned action to investigate the determinants of middle school earth science students' intentions to enroll in a high school science course. They included four blocking variables: ethnicity, gender, science ability, and general ability. The prediction of behavioral intention was tested using four external variables: attitude, subjective norm, attitude and subjective norm alone, and disaggregated data on attitude and subjective norm. Results revealed attitude and subjective norm to be the sole predictors of behavioral intention for the aggregated data, but to be differentially effective for groups formed on the blocking variables.

Myeong applied the theory of reasoned action and investigated the determinants of track choice by Korean high school students. The study involved 665 first year high school students. They completed questionnaires developed to match the theory of reasoned action and also to provide data on external variables like self-concept and demographies. The results support the theory of reasoned action. Subject norm had a small influence on behavior but not on intention, and gender, self-concept, and parental influence had differential effects.

Ray applied the theory of reasoned action to ascertain students' intentions to engage in science laboratory activities. Included in the study were 377 public school 46 private school and 34 home school students. Student attitude toward and their subjective norm with regard to science learning behaviors explained a significant amount of variance in intention to do laboratory and non-laboratory activities. Home school students had more positive attitudes toward laboratory. The previously documented drop in intention to do science was corroborated as between the 6th and 8th grades.

A different approach was taken by **Nolen and Haladyna**. They described "the relationships between individual differences in motivational orientation and the extent to which students reported deeply processing new information in science texts" (p. 116). Three-hundred-ninety-one high school students from a variety of courses and grade levels were given a Strategy Value survey to determine the strategies students saw as useful in understanding text; a Motivational Orientation Survey to determine if students were task, ego, or work avoidance motivated; and a Science Survey to measure attitude toward science, their perception of the importance of learning science, and their perceived ability. Correlational and regression analyses indicated that students belief in the usefulness of deep processing strategies was more strongly related to task orientation than to ego orientation across ages and abilities. The authors suggested that subsequent research should examine ways in which teaching behaviors can promote a task orientation and a commitment to deep processing strategies.

A complementary study by **Lee** identified patterns of task engagement, the key factors related to those patterns, specifically motivation. The study was based primarily on in-depth classroom observations and clinical interviews and other formal and informal interviews of twelve grade six students. The observations were taken as students engaged in a unit on kinetic molecular theory based on a theory of conceptual change. The results showed six patterns of task engagement ranging from high quality task engagement to achieve a scientific understanding to low quality task engagements to attain other goals. The patterns were related to students' interpretation of classroom tasks, their success or failure at understanding, their general goal orientation, and their affective orientation.

Shrigley discussed the implications of using science attitude scales to predict science related behavior. He pointed out the limitations associated with valid measurement and mediating variables such as individual characteristics, the social situation, and cognitive factors. He suggested that the relationship between attitude and behavior is reciprocal, not necessarily one directional. He also suggested that an alternative to attitude testing might be direct appraisal of classroom behaviors.

Attitudes Toward Reading

Two studies provided status information about student perceptions of science reading. **Simpson and Oliver** provide a summary of the major influences on attitude toward and achievement in science among adolescents. The summary is based on data from a longitudinal study of the effects of home, school and individual influences. The initial data were collected in 1980 from 328 sixth graders, 1031 seventh graders, 1031 eighth graders, 288 ninth graders, and 1830 tenth graders in a large school system in North Carolina. Students completed attitude and achievement measures three times during the year, as well as questionnaires. Teachers completed two attitude instruments (toward science and toward science classes) and were rated by science supervisors on a 50-dimension professional characteristics scale. A second set of data was collected during the 1985–86 school year from school records about the students' selection of science courses, course grades, participation in science activities, etc. The data were examined to determine the best predictors of future science behavior. Many relationships were found, both overall and by gender and race. The initial data were good predictors of science outcomes. The authors go on to present a model of influences that shows different influences being more prominent at different grade levels. At elementary school self and home influences lead to early experiences with science. This construct then influences attitude and achievement in middle school science which leads to a science self concept. This self concept influences selection of and achievement in high school science classes. This high school experience influences the subjects' life-long commitment to science.

Yore and Craig surveyed middle school student knowledge of science text and reading in Canada. Standardized interviews, word associations, concept maps, and object examinations were administered to 85 grade 5 students. Results of the interviews show that grade 5 students have reasonable declarative, procedural, and conditional knowledge about science text and reading but growth is necessary for them to become efficient successful readers.

Additional Studies

The remaining six studies investigated the relationships among student attitudes and other variables. **Dimit** examined the relationships among junior high school student attitude and personal, home, and school environment variables. Students whose mothers were well educated and employed in white-color positions gained in attitude with science project completion and science fair involvement.

Hatch examined the relationships among several personal characteristic variables and student interest in science for 185 high school biology students. Only three of the many variables, influence of a role model, encouragement of a significant person, and achievement in biology, correlated significantly with level of interest in science.

Harvey examined the relationships between experience with vegetation on school grounds and their attitudes toward the environment. Levels of past and present experiences of 8-11-year-old children from 21 schools in England were determined and compared to botanical knowledge and environmental dispositions. Data indicated that experience fosters more positive results.

Melear investigated the relationships between learning style, as measured by the learning style profile, and personality type, as measured by the Myers-Briggs, and other student characteristics and outcomes in an introductory college biology class. Introversion and spatial ability were shown to predict success and different profiles were found for majors vs. non-majors.

Wareing conducted an investigation of the relationships among student attitudes toward science and several variables that could be antecedents to these attitudes. Data were collected from 1740 students in 87 high schools. Results indicate a significant correspondence between report card grades, degree of structure, degree of stress, gender, degree of awards, and number of tests with student attitudes toward science.

Yahya examined the effects of nonschool factors in the attitudes toward science of 817 11th and 12th grade students in Iraq. The major findings were that grade, educational level of the parents, and frequency of watching television were related to student attitude in the anticipated directions.

Reviewer Comments

One thing that stands out in this set of papers on student attitudes and preferences is the high number of correlational studies. Although these types of studies are important, more studies should be directed toward the development of theory in science education attitudes. Some of the articles do advance theory, but a more in-depth look at the psychology literature and its relation to science education would probably be fruitful. More attention should also be directed toward discussion of the appropriateness of attitude as a goal of instruction and to the many varied components of attitude as a construct. With respect to studies of student motivation, in-depth studies of the specific factors that influence students' choice to engage or not engage in various classroom tasks and choice to adopt or not adopt deep processing strategies may provide an enriched understanding of students academic behavior.

Equity Issues in Science Education

Previous research and National Science Foundation reports indicate that women and minorities are underrepresented in technical careers over the last two decades. In 1990, there were 21 studies that investigated gender or race differences in science attitudes, interests, or achievement. Of these, eleven were articles published in refereed journals, six were dissertations, three were papers presented at national meetings, and one was a research report. There were three broad categories of investigations: seven studies reported the status of gender or race differences in science attitudes or achievement; eleven studies dealt with factors effecting gender or race differences in attitudes and achievement; and three studies reported evaluations of intervention programs for minority students.

Status Studies

Race and gender differences in science learning have received much attention in recent years. In 1990 there were seven papers that reported investigations of gender or race differences at various grade levels. One paper dealt with K–12 gender differences in Israel. Two papers dealt with gender differences in elementary school children, and one paper dealt with gender differences in early adolescents (grades 7–9), and two papers dealt with both gender and race differences of secondary students.

The purpose of the study by **Friedler and Tamir** was to determine whether the gender-difference trends reported in the literature apply to the learning of science in Israel. They analyzed 40 studies conducted in the last 15 years which compared Israeli male and female students' achievement in biology, chemistry and physics, level of cognitive functioning (knowledge, comprehension and application), inquiry and formal reasoning skills, and attitudes toward science and science learning. In the elementary school, there were no gender differences in attitudes toward science, achievement in biology, in application or inquiry skills, and only a small advantage to boys (about one-quarter of a standard deviation) in knowledge and comprehension, and in achievement in the physical sciences. Very large gender differences exist by the end of junior high school, however, in attitudes toward science, achievement in biology, chemistry and physics, all levels of cognitive functioning, and in inquiry and formal reasoning skills. Only 34% of the students who elect to take specialized science subjects in the senior high school are girls.

By senior high school (grade 10), when students make their choices of specialized fields of study in grades 11 and 12, an interaction between gender and science discipline begins to emerge. Boys are more oriented towards physics and engineering (only 31% of physics majors are girls), while girls are more oriented towards biology (60% of the biology majors are girls), with chemistry in the middle. Within biology, girls have a higher preference than males for studying botany, and a stronger reservation about using live animals in the study of biology. Among the students who specialize in science, there are no gender differences in achievement in biology or chemistry, but males excel in physics. In level of cognitive functioning, males excel only in application. Females consistently exhibit more positive attitudes toward practical laboratory work in all subjects, including physics.

Elementary

Shaw and Doan obtained similar results for elementary school students in the US. They investigated the difference in attitude toward science (Nyberg and Clark Attitudinal Scale) and science achievement (Stanford Achievement Test) between boys and girls in grades two and five. The subjects were 69 boys and 60 girls in second grade and 79 boys and 75 girls in fifth grade who were randomly selected from 51 elementary schools in a southwest Alabama city. There were no significant gender differences in achievement or attitudes towards science at either grade level.

The purpose of a correlational study by **Tracy** was to examine the possible relationships among children's extracurricular toy-playing habits, sex-role orientations, spatial abilities, and science achievement. The subjects were 139 girls and 143 boys from 13 different 5th-grade classrooms in a midwestern, suburban district. Science achievement was measured by the *Iowa Test of Basic Skills - Science* subtest. Spatial ability was measured by the spatial subtest of the *Educational Assessment of Ability*. This test requires subjects to "mentally rotate" two-dimensional figures rapidly and accurately. A modified version of the *Bem Sex-Role Inventory* was used to categorize students' sex-role orientations as undifferentiated (low feminine-low masculine), masculine (low feminine-high masculine), feminine (high feminine-low masculine), and androgynous (high feminine-high masculine). Finally, the author developed the *Tracy Toy and Play Inventory* which was used to categorize students as low or high playing for each of six types of toys: two-dimensional toys (e.g., jigsaw puzzles), three-dimensional toys (e.g., Lego blocks, Playdoh), estimated-movement-with-a-target toys (e.g., ping pong, video games), gross-body-movement toys (e.g., roller skates, sled), proportional-arrangement toys (e.g., toy farm set, doll house), and science-activity toys (e.g., rockets, microscope).

Boys had significantly higher spatial skills (mental rotation) than girls. No significant differences in spatial ability were found among students with the four different sex-role orientations. This result was unexpected, since other researchers have found sex-role differences in spatial perception and spatial visualization tasks in favor of masculine sex roles. No significant differences in science achievement were found between boys and girls, or among students with different sex-role orientations. However, students who had high spatial ability also had significantly higher science achievement scores than students with low spatial ability. There were no significant differences in science achievement between students with low and high toy-playing habits for any of the toy categories. There were, however some interesting and unexpected interactions. For example, femininely oriented boys who reported low playing behaviors in all toy categories except three-dimensional toys scored very well on the science achievement test. Historically, this "sissy" group has not received wide acceptance from parents, teachers, or peers. Negative feedback directed toward this group to not act "like a girl" may be unfounded. On the other hand, femininely oriented girls who reported low-playing behavior in all toy categories had very poor science achievement scores. The author suggested that the feminine attitudes and behaviors which teachers and parents stress may be intellectually stifling for these girls.

Secondary

Shemesh investigated gender-related differences in the relationship between the development of formal reasoning skills and learning interests during early the adolescent stage. 249 7th, 8th and 9th graders enrolled in three urban schools in Israel were administered a videotaped group test of formal reasoning based on Lawson's group test of formal operations. The students were also asked to write down the two subject fields in which they were most interested. These fields were categorized as science, math and technology (e.g., chemistry, algebra, computers), humanities and social studies (e.g., literature, history, economics), and arts, foreign languages, and physical education (e.g., drawing, French, basketball). The results indicated that boys mastered the quantitative formal operations (proportions and probability) earlier, and to a greater extent than girls. Boys tended to prefer science, math and technology subjects, and their learning interests did not change notably from 7th- to 9th-grade. On the other hand, girls interests do change significantly from 7th- to 9th-grade away from science and math and toward the arts and social sciences. Interests in science, math and technology fields were positively correlated to the development of formal reasoning skills for both boys and girls The author suggested that these gender differences in learning interests and formal reasoning may explain the increased gender gap in science achievement from ages 13 to 17. Boys' sustained general interest in science, math and technology increases their motivation to learn these subjects, and their early acquisition of formal reasoning patterns helps them cope with the new abstract scientific concepts in high school. On the other hand, girls formal reasoning at this age is not crystallized yet, and their learning interests shift towards language, social studies and the humanities. As a result, their science achievement in high school may be significantly lower than the science achievement of boys.

Hill, Pettus, and Hedin developed A Science Career Predictor Scale to assess seven attitude variables involved with science career choices: academic self-image, ability in mathematics and science, participation in science-related hobbies and activities, perceived relevance of mathematics and science, science-related career interest, teacher/counselor encouragement, and parental encouragement and support. Each variable was measured by six statements to which students responded using a 5-point Likert scale ranging from completely agree to completely disagree. The effect of such factors as gender, race, personal acquaintance with a scientist, and type of community (rural, urban) on the seven career-choice dependent variables was examined using a multivariate analysis of covariance with age as the covariate. The subjects were 522 students (227 males, 295 females; 240 whites, 282 blacks) randomly selected from middle and high schools in 20 school districts and 185 black students (75 males and 110 females) at an historically black university in Virginia.

There were no significant differences in the number of mathematics and science courses taken by the male and female students. Females had significantly lower attitude toward participation in a science-related activities and interest in a science career than males. There were no significant gender differences in mathematics and science ability, perceived relevance of mathematics and science, teacher/counselor encouragement, or parental support. While there were no gender differences in academic self-image for the public school sample, college females had a significantly higher academic self-image than college males. Public school black students had taken significantly more math and science courses than whites. Blacks had a significantly higher attitude toward participation in science activities, teacher/councilor encouragement, and total scores than whites. There were no significant race differences in academic self-image, ability in mathematics and science, interest in a science career, perceived relevance of mathematics and science, or parental support. However, in a study of 81 high school students administered the Watson-Glaser Critical Thinking Appraisal, white students scored significantly higher than black students, and there were significant correlations between critical thinking scores and the total score on the Science Career Predictor Scale and with the ability subscale. Across both races and both sexes, the major factor affecting science-related career decisions was personal acquaintance with a mathematician or scientist. The authors concluded that many of the barriers for females and blacks, such as academic self-image, ability in science and mathematics, teacher/counselor encouragement, and number of science courses completed, are no longer major factors in the underrepresentation of these groups in technical careers (at least for students in central Virginia). For females, the critical variable appears to be lack of science career interest, which is also reflected in lower attitudes toward participation in science activities. For blacks, critical thinking ability may be a major barrier.

Gordon examined the characteristics and college degrees of a sample of 10,536 individuals in the US who were high school seniors from the 1980 High School and Beyond Study and who responded to the 1986 follow-up questionnaire. Approximately 18% of the students had graduated with bachelors degrees. Slightly fewer than one in four college graduates (23%) had majored in science, engineering, or mathematics. The proportion of males who graduated with majors in science, engineering, or mathematics (31%) was almost twice as high as the proportion of females (16%). This disparity does not appear to be due to high school grades. For example, nearly one-half of the male graduates who had earned straight "A"s in high school (48%) majored in science, engineering, or mathematics, but only about one-quarter of the females with straight "A"s (26%) did. Although females who graduated from college generally had higher grades in high school, they did not necessarily take the same courses as males. Male college students, more often than their female counterparts, took physics (54 % versus 33%), calculus (31% versus 21%), and trigonometry (68% versus 59%) in high school. Even with the same courses, however, a higher proportion of males graduated from college with majors in science, engineering or mathematics. For example, more than half (53%) of the males who took calculus in high school majored in science, engineering, or mathematics, but the proportion of females who followed the same pattern was smaller (36%). As might be anticipated from these data, the proportion of females in high school who *intended* to major in science, engineering or mathematics in college (18%) was lower than the proportion of males (34%). Moreover, females who intended to major in science, engineering or mathematics were less likely to actually graduate with a major in one of these fields (44%) than their male counterparts (54%). There were no significant differences among whites, blacks and Hispanics in the proportion who majored in science, engineering, or mathematics. However, both Hispanics and blacks graduated from college in disproportionately small numbers. Although Hispanics represented 9.3% and blacks 11.4% of all high school seniors, the proportion of those who were college graduates was far smaller (3.7% for Hispanics and 6.5% for blacks).

Similar results were provided in a status study by **Horn**. The study was a descriptive summary of the changing trends in high school classes from 1969 to 19o7 using data from ETS's Study of Academic Prediction and Growth (1969), The National Longitudinal Survey of Labor Force Experience, Youth Cohort (1975-78 and 1979-1982), High School and Beyond (1982), and NAEP's Transcript study (1987). Twenty-eight displays of the data are provided which highlight gender and racial/ethnic group differences. In 1969, students earned a relatively high numbered credits in math and science. The numbers of credits completed by men declined from 1975-1982, and then credits for both men and women increased. All racial/ethnic groups made gains in total credits from 1969-1987 especially Hispanic students.

Reviewer Comments

Overall, these studies confirm that there are no gender differences in attitudes, interests, and general science achievement at the elementary school level. Boys appear to have significantly higher spatial ability (mental rotation), and a slight advantage in physical science achievement. At this age, children's' sex-role orientations (undifferentiated, masculine, feminine, or androgynous) and toy-playing behavior do not effect their science achievement. By the end of 9th grade, however, there are substantial gender differences in attitudes towards science, inquiry and formal reasoning skills and science achievement. While boys' interest in science remains high, girls' interests shift away from science and toward language, social sciences and humanities. The differences in attitudes and interest persist through high school; girls are less likely than boys to take courses in trigonometry, calculus, and physics, and fewer intend to pursue careers in science, engineering, or mathematics. Almost twice as many males as females graduate from college with majors in science, engineering, or mathematics.

Several authors concluded that the most urgent need is to improve the attitude and achievement of girls at the junior high level. This would require careful examination of curriculum and instruction grades 5–9, and the implementation of strategies, activities and curriculum materials which would attract girls, challenge their curiosity, and enhance their achievement. Shemesh suggested one avenue to new modes of instruction that might preserve adolescent girls' interest in science is research to find out the exact patterns of reasoning in which boys and girls can excel and the specific ways in which science instruction can accommodate these differences. In the case of minorities, the causes of the problem of underrepresentation seem to be more complex. Attitudes and interest of minorities in science-related careers appear to be as high or higher than for whites, but the number of college graduates remains low. Hill, Pettus, and Hedin suggested that further research is needed in intervention programs aimed at the effective use of role models and improvement of critical thinking skills.

Factors Effecting Race and Gender Differences

Several cultural, social and classroom factors have been suggested to account for race and gender differences in science attitudes, interests, and achievement—career-related stereotyping; lack of professional role models; lack of encouragement by parents, teachers, and counselors; lower expectations of self-efficacy; school environment; and differential treatment by teachers. In 1990, three studies dealt with academic or science self-efficacy, three studies dealt with gender and type of school, and three studies dealt with the differential treatment of students by teachers.

Gender Differences in Self-Efficacy and Anxiety

Gender differences in student's level of anxiety and their belief or confidence in their ability to do well in science courses (self-efficacy) have been hypothesized as contributing to differences in course enrollments and achievement. In 1990, there were three studies in this area.

Tippins investigated the relationship between science self-efficacy and gender and ninth grade students' intentions to take elective science courses in high school. A test of science self-efficacy for technical skills, tasks, problems, and science-related course work and a more general academic self-efficacy test were developed and administered to ninth grade students in eight Texas high schools. Science self-efficacy was found to be only slightly related to general academic self-efficacy. Boys had a slightly higher level of science self-efficacy and intended to take more science classes than girls. Although gender and science self-efficacy accounted for 10% of the variance in intentionality, there was a negative correlation of self-efficacy and intentionality—high science self-efficacy scores were correlated with low intentionality for both boys and girls. This result was opposite to what was expected.

At the college level, a higher percentage of women fail to complete a scientific major than men. **Morell** investigated whether gender differences in self-efficacy and perceptions of department support contribute to the observed gender differences in retention patterns. Eighty-nine male and ninety female entering freshman engineering students were administered a measure of academic related self-efficacy; they indicated their degree of confidence in completing the engineering degree requirements with a grade of 'B' or better. After twelve weeks of instruction, a measure designed to assess perceptions of department support was administered to the students. After four academic quarters, subjects who left the university or changed majors were defined as non-persisters. Controlling for the background characteristics of the students (SAT math, high school GPA), the higher self-efficacy of males was found to be related to the significantly higher retention of males. In addition, perceptions of department support were shown to significantly distinguish persisters and non-persisters; students who remained in engineering rated the department as being significantly more supportive than students who left. The results of a stepwise discriminant analysis revealed that when the variance associated with SAT math, high school GPA, and self-efficacy had been removed, department support remained a significant predictor of retention.

Zoller and Ben-Chaim investigated gender differences in trait anxiety, examination-type preferences, and academic achievement in college. The sample consisted of 46 males and 106 females in a science teacher training program in Israel. Students were administered a 20-item questionnaire to assess their trait anxiety (e.g., "I lack self-confidence.") and a second questionnaire to determine the types of examinations they prefer to take and their rationale for their preferences. There were no significant differences in the trait anxiety levels between male an female college students taking required science courses. However, the anxiety level of the males dropped significantly from freshman to sophomore year, whereas the parallel drop for females is not significant. Significantly more females than males prefer take-home exams, and significantly more females are less prepared to take oral exams, regardless of their format. In addition, females are more likely to believe strongly that the type of exam constitutes a major factor in determining their final grade. For all students, the traditional-type exam (written in class, time limited, no support material allowed) was rated the least desirable. A subsample of freshman biology students were administered a test anxiety questionnaire (e.g., "I feel relaxed.") just before their midterm exams. For traditional in-class exams in mathematics and general chemistry, the test anxiety means were significantly higher than the trait anxiety means for both males and females. There were no significant gender differences in either test anxiety levels or achievement on these exams. For in the organic chemistry *take-home* exam, in which a higher level of thinking and problem solving is required than in the general chemistry exam, the test anxiety of all students dropped to the level of their trait anxiety. However, the female students (who prefer this type of exam) significantly outperformed males.

Reviewer Comments. The results of these studies with respect to academic self-image or self-efficacy appear to be contradictory. Hill, Pettus and Hedin found no significant gender or race differences in middle and high school students' perceptions of their academic self-image or ability in mathematics or science. Tippins found that 9th-grade boys had a small but statistically significant higher science self-efficacy score than girls, and science self-efficacy was only slightly related to general academic self-efficacy. Morell found that freshman male engineering majors had a significantly higher science self-efficacy than their female counterparts, and this was related to their higher retention. Since different measures of self-efficacy were used in these studies, it appears that self-efficacy may have several components for example trait anxiety studied by Zoller and Ben-Chaim. Further research is needed to clarify the relationships between general academic self-efficacy and science self-efficacy. In addition, additional research is needed in instructional strategies that will improve the self-efficacy of girls in middle and high school.

Gender and Type of School

Previous research has shown a relationship between gender differences in attitude and achievement and type of school attended. Girls appear to perform better in single-sex schools than in coeducational schools, although many studies are confounded by the influence of socioeconomic status (private schools in many countries tend to be single-sex and have students of higher socioeconomic status relative to government schools). In 1990 there were three studies that investigated the effect of school type on gender differences, one in Australia, one in Trinidad, and one in Kenya.

Young and Fraser investigated the degree to which science achievement varies by gender and type of school (private, Catholic, government, single sex and co educational) in Western Australia. Secondary analysis was done on statewide data collected for other purposes. The first sample consisted of 9803 9th grade boys (n = 5033) and girls (n = 4770) attending 96 coeducational schools (74 government, 11 Catholic, and 11 private schools). The second sample consisted of 1774 9th grade girls from 15 girls-only schools and 12 coeducational schools, and 1639 boys from 8 boys-only schools and 10 coeducational schools. For each gender, single-sex schools were matched with coeducational schools of equivalent socioeconomic status in a metropolitan area of equivalent sample size. Science achievement was measured by fifteen multiple-choice items common to the selected samples of students—five measurement items, five science-skills items, and five life science items. School means for boys and girls were the unit of analysis, and the mean science achievement of the schools was statistically adjusted for the socioeconomic status (SES) of the school.

There were no significant differences in overall achievement of boys and girls attending coeducational government, Catholic, and private schools. However, boys showed superior achievement on 4 items which were diagrammatic in presentation and involved the interpretation of scales and experimental data; girls showed superior achievement on three items which were descriptive in presentation and biological in content. These gender differences were greater in the government schools, and not significant in the private schools. Catholic schools had some gender differences, but not as many as government schools. Girls in single-sex schools achieved higher than girls in coeducational schools ($p = 0.051$), and boys in single-sex school achieved higher than boys in coeducational schools ($p = 0.011$). There were no significant differences between boys and girls attending either single-sex schools ($p = 0.354$) or coeducational schools ($p = 0.868$). The higher achievement of students in single-sex schools could be confounded by the absence of government single-sex schools.

Fraser-Abder investigated the effects of gender, school type (single-sex or coeducational schools, private denominational or government schools), parental occupation, and socioeconomic status on science achievement in Trinidad. The subjects were 977 6th-grade students (329 boys and 648 girls) from 15 randomly selected elementary school classrooms, 9 in denominational schools and 6 in government schools. The students have varied background—African, Indian, Chinese, Syrian, British, etc. Science achievement was measured by the 25-item science section of the practice test given to all 11+ students in preparation for the Common Entrance Examination for secondary school. The teachers were asked to supply each students' socioeconomic status (upper, semi-upper, middle, semi-middle, and lower) and parental occupations (Prof/management, teacher, lower-level management, skilled occupation, semi-skilled occupation, unskilled occupation). Each variable was analyzed separately, using individual test scores. Girls ($M = 16.5$) scored significantly higher than boys ($M = 13.8$) on the science achievement test. Girls from girls-only schools ($M = 18.1$) scored significantly higher than boys from boys-only schools ($M = 16.3$) and students from coeducational schools ($M = 12.4$). Students attending denominational schools scored significantly higher than students attending government schools. Parental occupation significantly affected students' science scores, as did socioeconomic status, in the expected directions.

Ndunda did a case study of 20 third-year secondary students (16 females and 4 males) from two schools in Nairobi, Kenya, a girls-only school and a coeducational school. The interview data indicated that young women resist science careers because of the potential conflict with their future roles as wives and mothers in Kenyan society. Girls in the coeducational schools were more likely than boys to have negative school science experiences. Girls in the single-sex school reported more positive experiences with science and held more egalitarian views about women's ability to study science and pursue science-related careers than girls in the coeducational school.

Reviewer Comments. The results of these studies are consistent with previous research indicating that girls have a more positive attitude toward studying science, are less likely to see themselves in sex-stereotyped adult roles, and have a higher science achievement when educated in single-sex schools than in coeducational schools. Young and Fraser suggested that further research into strategies to improve science achievement among girls should investigate the significance of the school environment in enhancing not only science achievement, but also attitudes toward science and science careers. What factors operate in single-sex schools that lead to the improved attitudes and performance of girls? Can these factors be implemented in coeducational schools?

Differential Treatment of Students

The fact that few or no gender differences are apparent until puberty suggests that socialization may contribute part of the explanation for these differences. Data from the National Assessment of Educational Progress (NEAP) indicate that both inside and outside the classrooms, boys have more opportunities to experience science. Several previous studies have suggested that even within the classroom, boys and girls receive very different educations. In 1990 five studies investigated gender and ethnic differences in classroom interactions between science teachers and students.

Contreras and Lee did an ethnographic study of the differential treatment 7th- and 8th-grade students in four science classrooms taught by two science teachers. One "enriched" science class and one "regular" science class was observed for each teacher. Mr. Olsen treated his two classes differently. In his enriched class (8% minority), he provided learning environments that allowed enriched students to gain better access to science content. In his regular class (48% minority), he made use of verbal expressions and nonverbal gestures that might lead students to disengagement in science learning. In addition, most of the minority students in his regular class were prevented from participating in the science field trip or other outdoor activities by the low "citizenship" grades given to these students. In contrast, Ms. Cole tried to treat her two classes equitably. She stressed the importance of fostering student learning and motivation for the regular class even more than for the enriched class. No student from her classes was excluded from the opportunity to participate in the science field trip based on the criterion of citizenship grades. The authors concluded that classroom practices and school policies (e.g., citizenship grades) can exacerbate the "cultural gap" that already exists between teachers and students and among students of different cultural and ethnic backgrounds.

Welborn conducted a case study to investigate how boys and girls in two junior high school classrooms differed in their verbal interactions with their science teachers and their attitude toward science as a school subject and as a possible career choice. Data included direct classroom observation, surveys, and interviews with teachers and students. Most of the instruction occurred at the lower level of Bloom's taxonomy of cognitive skills, even for students in the "college preparatory" track. There was no difference in the verbal interactions between boys and girls and their teachers. There was a general lack of information about science careers for students from in-school or out-of-school sources.

In a statistical study with a larger number of teachers and students, **Jones and Wheatley** did find gender differences in teacher-student interactions. They used a modified version of the Brophy-Good Teacher-Child Dyadic Interaction System to observe 30 physical science classes and 30 chemistry classes which contained 1332 students. Observations were made for for one class period for each of 24 female and 6 male chemistry teachers, and 19 female and 11 male physical science teachers. The majority of the students where Caucasian, middle class students from urban and rural communities. The coded behaviors were combined to form 14 dependent variables. For each variable, the male mean was higher than the female mean. Significant differences were found for five of the variables. Male teachers asked significantly more direct questions of students (1.00 per student) than female teachers (0.49 per student). Boys called out responses to questions (0.23 per individual) significantly more often than girls (0.10 per individual). They also tended to use louder tones of voice when seeking the teacher's attention than the girls, who appeared self-conscious and quiet. Boys also received significantly more praise from their teacher (0.14 per individual) than girls (0.08 per individual). Boys also asked significantly more procedural questions of teachers (0.08 per individual) than did the girls (0.07 per individual). Boys had a significantly higher mean (0.08 per individual) for behavioral warnings than girls (0.02 per individual). There were two significant warning interactions. First, male teachers warn boys ($M = 0.05$) and girls ($M = 0.04$) with approximately the same frequency, but female teachers have significantly more warning interactions with boys ($M = 0.10$) than with girls ($M = 0.02$). Second, physical science teachers have significantly more warning interactions with boys ($M = 0.12$) than with girls ($M = 0.02$), whereas chemistry teachers warn boys ($M = 0.03$) and girls (0.05) with approximately the same frequency

The authors suggest that many factors could effect the differential treatment of boys and girls in science classrooms. Teachers may have different expectations of students based on gender, so they subsequently treat their students differently based on these expectations. It is also probable that teachers give differential feedback to students as a control mechanism over student behavior. This may explain, in part, the observed differences in direct questions asked by male teachers and behavioral warnings for boys. It is also likely that teachers are responding to the different behaviors of their students rather than their gender or other background. Student initiated interactions, praise, and warnings are all directly related to student behaviors. It is also possible that the observed gender differences are a result of intrinsic student characteristics such as prior experience, competitiveness, or confidence. That is, students may enter schools with preset stereotypes already built into their personalities. All of these factors may contribute to the complex set of behaviors observed in science classrooms.

Previous studies have reported the influence of a few "target students" who dominated classroom interactions and received a disproportionate amount of the teacher's attention. Action-zone theory suggests that students who sit in the front row and center seats of other rows interact more with their teachers. In a further analysis of the teacher-student interaction data described above, **Jones** investigated sex differences in target students and the seating patterns of target students to see if there was a T-shaped action zone present in science classrooms. Four of the 60 chemistry and physical science teachers were dropped from the sample because their classes were involved in laboratory activities where the students moved around. Target students were defined as those students who scored more than one standard deviation above the class mean for total interactions. Analysis of variance for total interactions indicated that no T-shaped action zone was present in the 56 classes observed. Although there were more male target students (61%) than female target students (39%), the female students averaged more interactions per class session than the male target students. Target students (approximately 3 per class) received significantly more direct questions from teachers ($M = 1.67$) than non-target students ($M = 0.51$). They also received significantly more sustained feedback from teachers (0.57 versus 0.06), and more teacher-initiated private conversations (0.07 versus 0.03). Nearly one-third of all students observed in the study (29%) did not interact at all or were silent. The author concluded that the inequitable participation of girls in science classes may be exacerbated by the dominating effect of large proportions of male target students.

Similar results were obtained by **Wetherall**, who examined the relationships among expectations, attitudes, student-teacher interactions, student gender, and required versus elective science classes in four high schools. Results indicated that males substantially control science classroom discourse in both required and elective courses, that there were no differences in teacher initiated interactions for low, average, or high achieving students, that student attitudes toward mathematics, English, and science did not show differences, and that time was shown to exert an influence on student attitudes.

Reviewer Comments. These studies indicate that many secondary science teachers give differential treatment to male, female, and ethnic students in their classrooms. Previous studies have yielded similar results for elementary and middle school male and female students in subjects like reading and social studies. Further case studies comparing teachers who do and do not exhibit differential treatment of students may serve to identify useful alternative interaction patterns and strategies that could be more widely implemented. Further studies are needed that evaluate the effectiveness of preservice and inservice programs that sensitize teachers to gender and ethnic equity issues and teach them how to collect data on their own interaction behaviors, how to alter their interaction patterns, and in cases where students are perpetuating sex-role stereotypes, how to intervene so that *all* students participate equally in laboratory and other classroom activities.

Intervention Programs

It is widely accepted but not rigorously documented that intervention programs in high school are effective in increasing the science ability and interest in science-related careers of minority students. In 1990, there were two evaluations of intervention programs, one for underachieving minority students, and one for high-ability minority students. In addition, there was one study of what types of interventions might improve achievement.

Mulkey and Ellis compared 112 underachieving minority high school students (primarily black and Chicano) who received some intervention with a control group ($n = 494$) from the same population who did not receive intervention. The students came from low-income neighborhoods in New York City and generally performed two years below grade level on national reading and mathematics achievement tests. Intervention was defined as participation in one or more of the following Urban Project programs: parent workshops, exposure to adult role models (scientists, parents, mentors), and participation in science clubs, supplemental classes in math and science, tutoring, or career counseling. Urban Project students were more likely to graduate from high school (72% versus 47%) and took more high school mathematics and science courses than their peers. Those who graduated were more likely to enroll in college (97% versus 80%). In college, however, they did not receive higher grades than their peers who did not receive the intervention, but went to college. The mean GPA for both groups was below 2.0. The largest number of courses failed by Urban Project students were English, composition, communications, and social science courses such as sociology and anthropology, which might demand higher levels of language skills.

Hayden and Grey examined the effect of participation in a Saturday Academy Program for high ability minority students (grades 6–11) on high school graduation rates, college enrollment, and choice of a major in a quantitative field. The Saturday Academy, held at the University of the District of Columbia, offers courses in electrical engineering, computer science, and mathematics (about 25 hours of instruction) for academically talented minority students, primarily 7th, 8th, and 9th graders. The subjects were 69 alumni (38%) of the 1983 program who still lived at the same address. The control group consisted of 50 (37%) students who were 9th graders in 1983, still lived at the same address, and who had the same academic profile as the Saturday Academy participants. The subjects were contacted by telephone and asked questions from a prepared survey form. The program was successful in improving high school graduation rates and college enrollment. Only 1% of the Academy alumni did not graduate from high school compared to 24% of the control group. 91% of the Academy alumni enrolled in college, compared to only 46% of the control group. Almost one-half of both college groups (49% of Academy alumni and 43% of the control students enrolled in college) selected majors in quantitative fields. The Academy program had a greater effect on the male participants than the female participants. One hundred percent of the male alumni enrolled in college and 59% chose a quantitative major. Only 87% of the female alumni enrolled in college, and 38% chose a quantitative major.

Reviewer Comments

The results of these studies are very encouraging, and support the contention that intervention programs are effective in improving high-school graduation rates and enrollment in college. The authors made two recommendations for further research. First, more systematic longitudinal tracking of students through college graduation and into graduate school or careers is needed to determine the proportion of intervention program students who enter science-related careers. Second, more information needs to be gathered about the effectiveness of specific intervention strategies (e.g., hands-on activities in courses, degree of parental involvement, mentoring by appropriate role models, etc.) so that interventions having less impact can be eliminated from programs, and those practices shown to be effective can be standardized and adopted across institutions. For example, **Baker** studied 268 twelfth grade students who had not enrolled in a senior science course to determine what correlated with the science achievement of white, black, and Hispanic male and female students from an urban school district. The significant predictors of achievement were verbal ability, the teacher using students' ideas in planning instruction and the teacher discussing possible careers in science with their students. Additional studies to determine which intervention strategies are particularly helpful are needed.

Students with Special Needs

There were only five investigations of students with special needs, two dealing with the learning disabled, and three with gifted students. Three were articles published in refereed journals, one was a dissertation, and one was a paper presented at a national meeting.

Learning Disabled Students

The purpose of a study by **Bay et. al.** was to compare the effectiveness of direct instruction and discovery teaching approaches on mildly handicapped and non-handicapped students' science achievement. Students were randomly assigned to the two treatments. The content of the lessons remained constant for both treatments and focused on prediction and identifying and controlling variables within the context of displacement and floatation. The results showed that students in both treatments learned equally well as measured by an immediate posttest. However, students in the discovery approach treatment outperformed the students in the direct instruction treatment on a retention test administered two weeks after the posttest. Learning disabled students in the discovery treatment performed better than their direct instruction counterparts on a performance-based measure designed to assess generalization.

Donahoe and Zigmond compared the academic performance of 86 [illegible] grade learning disabled students in mainstreamed science, social studies, and health classes with that of 87 low-achieving but non-handicapped students in the same classrooms. Low achievement students were defined as those with the lowest scores (third and fourth stanine) on the reading subtest of the California Achievement Test. The learning disabled students attended a resource room for instruction in reading, mathematics, or English two periods per day, and took all other courses within the mainstream program. Low achieving students earned higher grades than their learning disabled peers in social studies and health; there was no significant difference in the distribution of science grades. 69% of the learning-disabled and 56% of the low-achieving students earned a grade of D or less in science.

Based on standardized achievement tests the nine [illegible] high schools were divided into high, medium and low achievement schools. Neither learning disabled nor low achieving students earned different grades in health or social studies as a function of attending high-, medium-, or low-achieving high schools. In science, however, these students in high-achieving schools were unable to attain the same grades as their counterparts in middle- or low-achieving schools. The teachers in the high achieving schools set higher performance standards than teachers at the medium- and low achieving schools. Of the three variables (intelligence quotient, reading level, and absence rate), only absence rate discriminated between learning disabled students who passed or failed ninth grade. The authors suggest that if the purpose is social interaction with non-handicapped, mainstreaming [illegible] disabled students [illegible] appropriate. Based on the high percentage of low grades, however, the students were not [illegible] much. The authors concluded that [illegible] students may need direct instruction in learning strategies and organization [illegible] mainstream academic subjects, and consultation with mainstream teachers to increase the likelihood that learning disabled students actually learn science in their mainstream classes.

Gifted and Talented Students

Miller did a study to determine if traditional selection criteria (IQ scores >120, reading scores two years or more above grade, and positive teacher recommendations) were valid in identifying gifted elementary grade science students. These criteria were used to select gifted and regular 5th and 6th grade students who participated in an eight-week gifted science program. Although the gifted students possessed significantly higher science achievement scores (Metropolitan Achievement Test), they did not develop significantly different scores in problem solving skills (Monmouth Problem Solving Test), or more positive attitudes towards science (Science Attitude Inventory), school (School Attitude Measures), or themselves (Tennessee Self Concept Scale). The author concluded that the traditional selection criteria lack precision. He also concluded, based on correlations, that a tests of field independence (GEFT), formal thought (TOLT), and creative thinking (Torrance Tests of Creative Skills) may be valid additions to the selection criteria used to identify gifted 5th and 6th grade science students.

Lynch(a) presents evidence that academically talented youth (about 1 in 200 students) can master high school science in about one-half of the time and about two years earlier than currently permitted in most science programs. Equivalent forms of the CEEB Achievement Tests (range 200–800) were given as pre and post tests to 918 academically talented students (aged 12-16) who were enrolled in 43 biology, chemistry, or physics summer courses (82 hours of instruction) from 1982 to 1987 at John Hopkins University. Average gain scores were 154 points in biology, 202 points in chemistry, and 108 points in physics. The average posttest scores, converted to percentiles for comparison with the norm group of college-bound high school seniors, were 73rd percentile in biology, 77th percentile in chemistry, and 70th percentile in physics. Lynch argues from developmental and cognitive science research, that high academically talented students should take high school courses earlier. She proposes a curriculum for the academically talented: physical science in the 6th grade, earth science in the 7th grade, biology in the 8th grade, and physics, AP biology, AP chemistry, and AP physics as choices for the 10th, 11th, and 12th grades. The suggested curriculum model would integrate a well-developed content base with inquiry methods which encourage critical thinking.

In a further study, **Lynch**(b) investigated the proportion of academically talented students aged 12 to 16 who pursued appropriate school placement or credits for course work they completed special summer academic programs. One-thousand-two-hundred-fifteen students who had completed a mathematics or science summer course sponsored by John Hopkins University were sent a questionnaire. Forty-seven percent (570) of the questionnaires were returned. Of the 320 students who took summer courses designed to replace traditional high school courses, 69% (222) requested credit or placement, and 80% of those (178) received it. Most requests for appropriate placement (88%) were honored, but fewer requests for credit (69%) were granted. Many schools asked student to take additional examinations before credit or placement would be granted. The author recommended the establishment of flexible but clearly articulated policies for recognizing standardized examinations as evidence of subject matter mastery and as a basis for rewarding credit. Otherwise highly talented students who enter high school early for advanced courses may not find the required number of courses to take to satisfy [illegible] school graduation credit requirements.

Reviewer Comments

The status study by Donahoe and Zigmond suggests that more attention needs to be paid developing and evaluating appropriate learning activities for mainstreamed learning disabled and low-achieving students in science. The results of the study by Bay et. al., are promising in this regard. The study by Miller indicates that some additional criteria for identifying gifted 5th and 6th grade students may need to be developed. The study by Lynch (a) is encouraging. It suggests the need for flexible scheduling for the 0.5% of academically talented students. Overall, the low number of studies of students with special needs suggest that continued efforts are needed to understand how to identify and help these students in our regular science classes.

Teacher Characteristics

There were 26 papers in the teacher characteristics category, 9 were dissertations, 4 were presented papers, and 13 were journal articles. These 26 papers were grouped into three categories. Eleven studies were classified as being descriptive of teacher characteristics. Five of these studies were surveys of teachers using a variety of instruments, usually questionnaires. Four used in-depth interviews or cases studies, one used concept mapping, and one used both observations and student data. The second category includes seven papers that report investigations of the effect of various types of experiences or specific interventions on teacher characteristics. Two of these studies involved pre-post testing of a large number of teachers. Five of the seven were more qualitative in their approach; two used in-depth interviews with smaller numbers of teachers, and two used concept mapping. The third category consists of eight papers that examined the relationships among teacher characteristics and other variables. Seven of these studies were correlational, but two also included observations of teacher talk or classrooms, and another included in-depth interviews.

Descriptions of Teacher Characteristics

There were a wide variety of teacher characteristics described in the eleven papers of this set. Two studies provided demographic information about teachers and their teaching practices; two studies described the characteristics of exemplary teachers; two studies examined teachers' scientific beliefs or world views; four studies described teachers' pedagogical or disciplinary knowledge, and one study reported variables that cause teacher stress.

Bobbitt summarized the National Center for Educational Statistics results from its schools and staffing survey. The data were obtained from a survey of 13,000 public and private school teachers and are presented in a variety of tables including characteristics such as sex, race, age, and marital status.

Tamir described the characteristics of senior high school teachers in Israel. The teachers were characterized on a large number of variables, and comparisons are made by gender, type of science taught, and age. Some of the findings were: Sixty percent of the teachers were female, but this ranged across the sciences from a high of 72% in biology to a low of 18% in physics. Of the three types of teachers, biology teachers were the youngest, the most progressive, and professionally most active. Teaching conditions were viewed as adequate. Laboratory work was common, with the least done in chemistry. Field work was not common, and if done, it was usually done in biology classes. Teachers who were more professionally active provided more experiential and individualized instruction.

Two studies provided characterizations of exemplary teachers. **Burtch** compared the characteristics of the typical K-8 teachers to the characteristics of exemplary science teachers. Data were obtained from "A study of Schooling" which had information on 231 elementary classroom teachers. An exemplary science teacher portrait was developed with four components: science methods, philosophy and attitudes, personal growth and time, and involvement. These served as the criteria for the model. The conclusion was that only 13% of the teachers met the criteria as an exemplary elementary science teachers.

Tobin and Fraser described what it means to be an exemplary science teacher. Twenty exemplary Australian teachers were observed, and data were collected from their students. Exemplary teachers used management strategies that facilitated sustained student engagement, used strategies designed to increase student understanding of science, utilized strategies that encouraged students to participate in learning activities, and maintained a favorable classroom learning environment.

Two studies provided descriptions of teachers' scientific beliefs or world views. **Eve and Dunn** examined the extent to which 190 life science/biology teachers held pseudo-scientific beliefs. It was found that many teachers did hold these beliefs, e.g., the Bible as an authoritative source, creationism, Atlantis, Big Foot, psychic power, and reincarnation.

Groves investigated the beliefs and professional backgrounds of secondary school science teachers from a public and a Protestant Christian school. It was found that the teachers were different in regard to their world view and therefore in what was perceived as important in meeting the needs of their students. The two Christian school teachers believed in God and believed they must teach science in a way that agrees with their understanding of scripture. The public school teachers did not guide their students toward any set religious goals, had a naturalistic world view and a more or less nontheistic interpretation of the natural word. The major controversial issue was the teaching of the creationist view of origins or the evolutionary view.

There were four studies that dealt with teachers' disciplinary or pedagogical knowledge and teaching practices. **Roberts and Chastko** examined preservice teacher conceptions of thinking about teaching using the Science Teacher Thinking Framework (STTF). There are four components of the framework: subject matter, teaching strategy, objectives, and student response. Preservice students in a methods class were asked to use STTF as a lens through which to view a video taped lesson segment. The authors present excerpts from class discussions while viewing the tape. The authors identified different types of responses to issues in discussion and conclude that STTF is a useful framework for organizing thinking about lesson or curriculum.

Smith used a case study approach to investigate an elementary school teacher's theories and beliefs. Interviews, written notes, observations, and audio recordings were used to document the teacher's thinking about a unit throughout the school year. The relationship of thinking and practice was compared to Schon's account of the reflective practice of professionals to develop a model of the teacher's theories, planning, and thinking-in-action.

Hoz, Tomer, and Tamir used concept mapping to examine the pedagogical and disciplinary knowledge of teachers. Data were collected from seven biology and six geography teachers with short or long teaching experience. The concept maps were analyzed along five structural dimensions to determine whether: (a) the disciplinary knowledge of teachers is better than their pedagogical knowledge; and (b) the pedagogical and disciplinary knowledge of teachers improves with teaching experience. The authors concluded that both the disciplinary and pedagogical knowledge of the teachers were unsatisfactory; that neither type of knowledge improved with length of experience; that pedagogical knowledge deteriorated slightly over time; and that the disciplinary knowledge was better mastered than the pedagogical knowledge.

Hauslein examined the effect of teaching experience on the biology content cognitive structure of teachers. Five groups were studied, preservice teachers, inservice biology teachers with 1–3 years of experience, inservice biology teachers with 5 or more years of experience, biological scientists, and college seniors majoring in biology. The results show that the teachers with the most experience teaching had more organized cognitive structures than the preservice and 1–3 years of experience teachers, and the 1–3 years of experience teachers had more organized cognitive structures than the preservice teachers. The transition appears to be one from a fairly large, loosely organized pool of biology concepts to one which is highly structured but limited to the expectations of the curriculum taught.

In the final study in this section, **Okebukola and Jegede**(b) investigated variables that cause stress for teachers in Nigeria. The ratings of 206 teachers showed the following top six stressors in descending order: (a) difficulty obtaining equipment and material; (b) having to cope with teaching traditionally difficult topics; (c) inability to complete the syllabus on time; (d) having to teach subjects in which they were not trained, (e) having to cope with the demands of new curricula; and (6) poor attitude of students toward science lessons. Coping strategies included positive thinking about the importance of the role of the science teacher and sharing with colleagues.

Experience or Intervention Effects on Teacher Characteristics

There were seven studies that focused on changes in preservice or inservice teacher attitudes, beliefs, knowledge or teaching practices a result of different types of experiences or interventions.

Ganser investigated the influence of teaching experience on conceptualizations of good teaching among five beginning high school teachers from different subject areas. The perceptions and practices of the teachers were documented over one school year. The data show that students provided the greatest influence on the subjects' ideas about good teaching, although overall the subjects' beliefs about good teaching remained intact over their first year of teaching experience.

Tobin, Briscoe, and Holman made the case that elementary school science teaching is dominated by the view that knowledge is transferred from teachers and books to students. They also propose that this view of teaching is dominant because of constraints that teachers construct this view based on their prior knowledge, beliefs and experiences. Viewing constraints as the constructions of individuals rather than as external immutable barriers results in the view that constraints can be changed. This perspective is illustrated by a case study of one teacher who recognizes that knowledge is not simply transferred from teacher to student. She then confronts the perceived constraints to changing her initial view of teaching and learning, and, within a supportive social context, changes her instructional approach to be consistent with a constructivist view of learning and teaching. The authors claim that the case illustrates that is possible for a single teacher to overcome the perceived constraints on change and influence the instructional approach of others as well.

The remaining five studies reported the effects of specific experiences or interventions on teacher characteristics. **Demers and Shrigley** investigated the effect of videotape and written channels of communication on the attitudes of preservice elementary school teachers toward the teaching of science. The pretest, posttest, and retention test scores of 66 preservice teachers exposed to either video-tape communication or to written communication were subjected to an analysis of variance for repeated measures. Both types of communication were found to be equally effective.

Beyerbach and Smith had preservice early childhood education majors' (n = 17) use a computer program to construct concept maps of their thinking about effective teaching. The comparisons of the computer generated maps indicated students listed very similar streams of concepts related to organization, knowledge, classroom management, professionalism, communication and attitude throughout their experience. However, the final maps contained more information and more hierarchical organization. Reflections on their mapping exercises changed from emotional reactions indicating concern and frustration with the use of the computer to a sense of mastery. The later reflections also included more information about reflective teaching, more information from the course and more analytic comments about the computer program and concept mapping. The authors concluded that the computer concept mapping had been useful in tracking students changing knowledge about teaching.

Starr and Krajcik used concept mapping to investigate the change in a group of sixth grade teachers' perceptions as they revised a science curriculum. The maps were analyzed using three criteria: hierarchical structure, progressive differentiation, and integrative reconciliation. The changes made in the maps during the revision process show increased clarification of both the concepts to be learned and the connections between them. The authors conclude that concept maps can be used to help teachers develop science curriculum that is hierarchically arranged, integrated, and conceptually driven.

Clermont investigated the effect of a two-week workshop in how to do chemistry demonstrations on novice and experienced demonstrators' pedagogical content knowledge. Experienced demonstrators were shown to have a large body of knowledge about chemical demonstrations, their variations and inquiry strategies for presenting the information to middle school students. The workshop produced an increase in the number of chemical demonstrations, their complexity, their variations, and their use in promoting learning. These changes moved the novices closer to the characteristics of the experienced demonstrators.

Westerback and Long investigated the effect of improved teacher science knowledge on their levels of anxiety. The levels of anxiety toward teaching earth science of 95 in-service teachers were measured before and after a content-centered program. Content knowledge increased, and levels of anxiety were reduced.

Teacher Characteristics and Other Variables

There were eight studies that examined relationships among teacher characteristics and other variables. **Abiedu** explored the relationship among the personal and professional characteristics and attitudes toward science and technology of 362 preservice teachers in Cameroon. Four of the nine characteristics variables were shown to be related to attitude: age, previous science experience, teaching experience, and language of instruction.

Brekelmans, Wubbels, and Creton used Dutch, 15-year-old physics students' perceptions of teacher behaviors as a basis for examining the effect of behaviors on student outcomes. Student-perceived teacher behaviors correlated differentially with attitude and achievement measures. Perceived teacher behaviors that are favorable for high *affective* outcomes are not the same as those that are favorable for high *achievement* outcomes.

Crawley used regression techniques to determine the relative contribution of three determinants on the intention of teachers to use 50% of the activities completed in a teacher training program with their students during the coming school year. The determinants as set forth in the theory of planned behavior were attitude toward the behavior, subjective norm, and perceived control over the behavior. Data were obtained from 50 Grade 5/6 or 9/10 teachers who had participated in a physical science institute. All three determinants were found to be significant predictors of behavioral intention with attitude toward the behavior the single most important variable.

Carlsen examined the relationships among teacher subject matter knowledge and individual classroom utterances in four new biology teachers. When teaching unfamiliar content, teachers talked for long periods of time, asked questions frequently usually at the low cognitive level, and had fewer student questions.

Marek, Eubanks, and Gallaher investigated the relationship between classroom teaching practices and high school science teachers' understanding of the Piagetian developmental model of intelligence and their understanding of the learning cycle approach. Data were collected from a sample of eight teachers who had attended an in-service program focusing on laboratory-based science curricula and the educational and scientific theories upon which the curricula were based. The eight teachers were selected to be representative of different levels of understanding of the learning cycle and the Piagetian model based on responses to essay questions. These teachers were then observed as they conducted science lessons in their classrooms. Teachers who exhibited a sound understanding of the Piagetian developmental model of intelligence and the learning cycle were more likely to effectively implement learning cycle curricula and were able to successfully integrate their students' laboratory experiences with class discussions to construct science concepts.

Matthews examined the effect of curriculum instruction orientation on teacher beliefs and practices regarding student science project development. Two instruments and a short demographic questionnaire were completed by 506 middle and high school science teachers. The six curriculum instruction orientations were academic rationalism, personal relevance, cognitive processes, technology, social adaptation, and social reconstruction. Significant differences were found among the orientations and student participation in science fairs/projects, percent of class time spent on laboratories, use of class time for the project, types of assistance provided, and beliefs in the importance of science fairs/projects. Elementary and middle school certified teachers rated science fairs higher than high school teachers.

Tuan and LaRussa examined the relationships among seven preservice science teachers' beliefs about science education and their lesson planning. Common beliefs included valuing science processes and understanding over memorization. The preservice teachers' beliefs were viewed as a dominant factor in planning lessons but not in easily predictable ways.

Walker examined the relationships between learning style and teaching style in secondary science teachers. These science teachers scored higher on the abstract and reflective scales than the general public. The Personal family scores were inversely related to the Active/Reflective Continuum. Behavior Modification was negatively related to abstract conceptualization, and a positive relationship was found between Social Interaction and Abstract Conceptualization.

Reviewer Comments

The large number of studies in this section reflects understanding that teachers play a key role in the achievement of science education. A great deal is known about teacher's knowledge, personalities and characteristics, and about how interventions affect these. What seems to be needed is more synthesis of these results and more investigation of the causal relationships between teacher characteristics and student outcomes.

Teacher Preparation

There were 19 studies in the area of teacher preparation. Seven o` these were published in referred journals, nine were dissertation studies, and three were papers presented at national meetings. Eleven studies were related to elementary school teacher education and five were related to secondary school science teacher education. One was a comprehensive study of how well small colleges meet NCATE certification standards. In all cases researchers addressed concerns about the qualifications of teachers and how teachers qualifications can be improved.

Elementary

The teaching of science in the elementary school has been described as limited and of low quality. One reason that has been proposed reason for this has been the preparation that teachers receive in science and science education. Five studies related to their preparation in science, two studies were reports of attempts to improve preservice science methods and four attempts to develop effective inservice were reported during the period covered by this review.

Preservice Science

Tilgner's review of the research literature indicated that teachers' attitudes and abilities with respect to teaching science were limited. Several possible reasons given for this were that: (a) teachers preparation in the sciences is limited, included little hands-on experience, and included little opportunity to learn science in the way they would be expected to teach science; (b) teachers anxiety about teaching science was not alleviated; (c) the priority given to teaching science was not high, and (e) teachers saw their responsibility as imparting information in contrast to the students who preferred active involvement in science. The primary recommendation was that teacher education programs should include science courses that would involve elementary teachers in extensive and diverse science activities. Such courses should allow elementary school teachers to interact directly with their environment and to understand that science is much more than a body of unrelated facts.

One attempt to improve the science portion of the teachers educational program was by **Hall**. The innovation was a biology course modeled after innovative elementary school science programs. The course was described as hands-on and discovery oriented. Hall was specifically interested in the improving preservice teachers attitudes because a negative attitude toward the teaching of science could have a serious and long-lasting impact on student and teacher performance. A single group pretest-posttest design was used to study the effect of the course on preservice teachers' attitude toward science teaching. The students were tested using the Revised Science Attitude Scale. The pretest-posttest differences for the 159 students were modest (approximately a 5% gain) but statistically significant. The author claimed that the course was effective in promoting positive attitudes. Other claims were that qualitative and experimental tests of the course were needed and that longitudinal studies linking classroom practice to teachers attitudes toward science were needed

DeTure, Gregory and Ramsey went a step further and coordinated a science methods course with a combined chemistry-biology course by adopting a theme such as classification for each week. During the methods course students learned related science processes that were to be used in the science course.as well as classroom activities that could be used with elementary children. During the science course students studied topics related to the weekly theme. Students in the combined chemistry–biology course were compared with students in a nutrition course that was often taken by elementary education majors. The scientific knowledge of the experimental group increased significantly, whereas that of the control group did not. No significant differences in the students' attitudes toward science and science teaching were found. The authors claimed that the initial offering of the course was moderately successful but that the magnitude of the change was not as great as was expected.

Finally, **Rice** provided a cooperative learning study of preservice elementary science students who took a physical science course for elementary teachers. The results indicated that there were no significant differences for achievement, practical skills, understanding of concepts, or attitude.

Preservice Methods

Attempts to improve science methods courses were also reported as part of our efforts to improve the preparation of elementary school teacher. **Pedersen and McCurdy** reported an assessment of the effects of an innovative preservice elementary science teaching methods on students' attitudes toward teaching science. The course consisted of one hour of lecture and two hours of laboratory experience each week. One major part of the laboratory experience was the peer teaching of science lessons from successful elementary science programs. Another important part was a two to three week practicum experience. The students from four successive quarters ($N = 145$) were pretested and posttested using the Revised Science Attitude Scale. The t-test comparisons of the pretest and posttest scores showed a significant positive gain for the whole group and no significant differences between the attitudes of low achievers and high achievers. The authors claimed that the results supported the view that teaching experience with inquiry oriented activities may positively influence the attitude of students. They also indicated that both high achievers and low achievers benefitted from the experience.

A second innovation in a methods courses was reported by **Klag**. The study was an experiment to determine the effects of SCIENCE - TIME (Science Training in Equipment and Materials). The program consisted of nine 1.5 hour sessions in which students completed carefully selected activities from earth science, life science, and physical science. The pretest-posttest control group study indicated that the instruction improved preservice teachers' attitudes toward science and their knowledge, familiarity and use of equipment and materials. The results also indicated a dramatic increase in the quality of hands-on instruction by preservice teachers in the classroom.

Inservice

In addition to the studies related to preservice elementary school science education. five studies related to inservice programs were reported: two on the use of trained teachers to present inservice, one on improving teachers self-efficacy, one on earth science inservice programs, and one on decreasing professional isolation.

Two of the studies were reported on the use of trained teachers to present inservice training. **Ross**(b) tested the use of key teachers to assist other teachers in improving the problem-solving skills of their fourth grade students. He argued that while there is a substantial research base indicating the value of teacher-teacher interactions, the use of key teachers to improve instruction has not been compared to the delivery of inservice to all teachers in a group. Two groups of teachers were used. One group of teachers from 20 grade four classes in nine schools were provided inservice instruction regarding the improvement of the problem-solving skills of their students. Another group of teachers. one from each of 10 schools of 24 classes, along with their school librarian, were provided the same training. They were then expected to return to their schools and, with the support of the school principal, pass the inservice on to their peers. The achievement of the students of the two groups of teachers were compared to determine the effects of the two approaches to inservice. The students were tested on the abilities to make comparisons and decisions. The results indicated that there were significant differences on both student outcome measures from pretest to posttest for both groups but no significant differences between the methods of delivering the inservice. The comparable effects at a lower cost suggests that the key teacher method of delivering inservice may be quite important. However. as Ross points out, there were a number of other attendant factors that were not tested that should be studied. Similarly, other enhanced key teacher programs that should be tested before adopting the approach uncritically.

The second study also reported positive results related to the use of trained teachers to present inservice teacher work shops. **Rowland and Stuessy** reported on a model for teaching elementary teachers basic process skills. The skills of interest were observation, classification. inference and prediction. The project included the development of a kit of materials consisting of video tapes and process skill activities for teacher mentors to use in providing inservice. After nine mentor teachers had been trained to use the kits, they returned to their districts to provide a one day workshop for their teachers. Teachers in the workshops generally responded favorably to the instruction provided by the mentor teachers and reported that they would be likely to teach science processes during the coming year. The teachers were also pretested and posttested using a process skills identification and use test. The pretest-posttest comparisons indicated statistically significant improvements in teachers ability to identify all the process skills they had been taught, improvements in their abilities to observe and classify, but no improvements in their abilities to infer or make predictions.

The third study that reported positive results was by **Moore** who argued that since teacher preservice programs require limited science, inservice is necessary to augment elementary teachers backgrounds. The expectation was that when the teachers content and beliefs are improved, the teachers self-efficacy would be improved and as would their teaching of science. One result of an intensive inservice program was that the self-efficacy of the teachers was improved significantly more than was the case for two control groups. The teachers in the program also taught more science, used different methods, and were more active than their counterparts in sharing science information with their colleagues.

Cox reported on a three part study of earth science inservice programs for teachers. One innovation was a special methods course that integrated teaching methods, the nature of science and process skills. The results showed significant pretest to posttest gains in the teachers self-perceptions of their abilities to teach science. The second part compared the effects of interactive videotaped earth science field trips to on-site trips and lectures. The videotaped trips were found to be more effective than the on-site trips and equally effective as the lecture. The third part was about the effects of a six week earth science institute that combined guided inquiry activities and field trips. The participants made large cognitive gains that were stable for up to two years.

The fifth study for this section was a report of the Better Elementary Science Teaching (B.E.S.T). telecommunications project to decrease the professional isolation of elementary teachers and improve their science knowledge (**Jinks and Lord**). Fifty teachers participated in a four week summer workshop in which they lived together, learned to use a state wide telecommunications system, and were taught science related to elementary school curricula by science faculty. Subsequent to the workshop the teachers became very active, using the network 15,000 times during the ten months following the summer program. A series of content area tests that were used as pretests and posttests demonstrated significant improvements in the teachers background knowledge. A more general test provided evidence of a positive shift in their science-like perceptions and their confidence with the content. The authors conclude that the telecommunications system was useful in overcoming academic isolation, but noted that it may not be an effective way to initiate professional relationships. The intensive workshop was seen as essential to establishing initial contacts and in developing the teachers' confidence in their ability to use the system.

Reviewer Comments

Contrary to well reasoned arguments that improving science courses for elementary teachers should improve their science teaching, the papers reporting on attempts to improve preservice science backgrounds cannot be viewed as encouraging. Perhaps the interventions were not sustained over a period of time that is sufficient to change students knowledge and attitudes. The reports of the efforts to change science teaching methods courses was somewhat more encouraging, as were the reports on inservice efforts. However, this comment must be considered with caution since the number of studies reported was limited and each represented substantially different approaches

Secondary

The research in 1990 related to the preservice education of secondary school teachers included six studies: three related to the quality or long term effects of preservice teacher education programs, and three related to the effects of specific features of preservice efforts.

8888Quality of Training

The first two studies dealt with the quality of the training preservice teachers receive. **Reeves** studied the qualifications of teachers in a single state using the National Science Teachers Association Standards. The results indicated that: (a) only 8% of the the state's science teachers were teaching out of field; (b) the teachers were well qualified according to NSTA certification standards for teaching experience, directed teaching, total and supporting science course work, and science methods; and (c) improvements in course work were needed within their specific discipline, mathematics and educational applications of computers. Given the existing criticism of science teacher education, this study is encouraging. However, **Brockway** was concerned with the qualifications of the faculties of small colleges who teach the science education components of preservice programs. The results showed that background in science and science education of small private college faculties who taught courses and supervised the students are very limited. Small numbers of students in these programs seemed to limit the colleges ability to hire specialists in science education.

The third problem was an investigation of the relationship between science teachers patterns of career entry, remaining and leaving and one of the variables relevant to teaching, their science knowledge. **Shugart** tested 83 individual teachers with respect to their science background and the pattern of their careers for as long as ten years. The results indicated that subject matter knowledge had a significant effect on both the likelihood of teachers being a non-recruit versus a career teacher and their being a Defector versus a Career Teacher.

Effects of Program Components

While studies of the quality of science teachers training and the long term effects are important, studies of what occurs "inside" science teacher education programs are also important. Four studies serve as examples of research of this type.

The first two studies investigated the transfer of the skills and concerns students developed during peer microteaching to student teaching (**Gess-Newsome and Lederman**(a)(b)). The research was conducted as a qualitative case study of 17 students in a secondary science teaching program. All seventeen students were studied during the microteaching and 6 of those students were studied throughout their student teaching. The students views were documented during critiques of videotaped microteaching sessions through an open ended questionnaire administered preceding and following their presentations. During student teaching, the students completed a similar questionnaire each week of their student teaching. In addition, the students' weekly seminar was audiotaped. Students' responses to the questionnaires and their seminar discussions revealed 12 categories of concern during microteaching and 17 categories of concerns distributed in two broad categories, concern for self and concerns for students. The concerns for self were in the areas of physical appearance/expression and confidence, audiovisual mechanics, lesson plan access, clerical/administrative skills, and work load. The concerns for students were in the of reaction to and cognizance of students, student involvement, instructional sequencing, concrete and relevant instruction, questioning, management, instructional planning, motivation, rapport, depth and breadth of material, and the time requirements for learning. The major findings were that as the students moved into their student teaching the number of areas of concern increased. They added the clerical/administrative work load, motivation, rapport, depth and breadth of material, and time requirements for learning concerns. The addition of the last four of these categories indicated a shift from concern for themselves to concern for their students. Another notable observation was that the students' perception of planning changed. During microteaching, planning was seen in two steps, the writing of the plans and the rehearsal of the plans. During the student teaching, planning was seen as the reviewing of content and then locating analogies, metaphors, stories or activities to best communicate the content. They rarely mentioned objectives in their responses to the questionnaire.

MacKinnon addressed the problem of how to conceptualize the dynamic process of the practicum in learning how to teach science. A theory of reflective teaching was used to develop a scheme for analyzing two case studies of a reflective practicum in constructivist science teaching. Application of the scheme was used to determine how the student learned to see the practicum setting as the teacher did, and how the teacher model of pedagogy is derived in part from the student's practicum experience.

Schneider examined the changes that occurred in preservice science teachers while they learned to teach. The results indicated that while these students learned a great deal by vicarious experiences there were several key aspects of teaching that were learned only enactively. These included the development of personal beliefs and values about teaching, changes in subject matter knowledge, and the development of pedagogical content knowledge. In-depth studies of preservice teachers in these settings are likely to become quite important in planning the specifics of what preservice teachers are asked to learn and the experiences they are provided.

Reviewer Comments

Studies of secondary science teacher education programs are likely to be critical to understanding and improving science education. Studies of preservice programs using the NSTA standards would allow for developing a national picture of the training of science teachers and cross state comparisons. For example, **Finson** assessed the impact of the new National Council for Accreditation of Teacher Education (NCATE) standards on small rural colleges and found specific ways in which many of these institutions did not meet NCATE standards. Studies investigating the qualifications of the faculties would provide complementary information regarding how many new teachers are being trained by individuals with more limited expertise than is desirable. Studies of the relationships among teachers' abilities such as their science knowledge with respect to the entry and leaving the science teaching also would provide information that could assist in our efforts to recruit, select and educate people who will remain as productive career teachers.

However, these studies will be of limited value if we do not learn how preservice students thinking about teaching develops, which of the teaching practices provided in methods courses are actually employed by students, and determine the types of experiences that are important for preservice teachers as they begin to enter the profession. If we are to really understand the effects of our programs and where changes in science teacher education are necessary, it may be especially important to trace changes in students' thinking from the entry of the students into their programs and at least until they have completed their first couple of years of practice..

In addition, studies of the professional lives of teachers and the inservice programs will be necessary. Research regarding how teachers' thinking develops throughout their professional lives would be important if we are going to attempt to improve the intellectual climate in which they work. Studies of the effects of inservice programs, interactions with their peers and others, advanced study, and the opportunity to develop curriculum on how they think about their teaching would be useful.

Policy Studies

The United States education system has been criticized for the poor performance of its students in science education on several international comparisons (Ferko). While there have been warnings that the results of such studies may not be providing information that warrants such severe criticisms (**Eichinger**), research such as this has been the basis for many discussions of reform efforts and policy changes. There have been a number of types of responses to these criticisms—attempts to learn from the policies of the past and the present, and attempts to predict the future. Fifteen studies that provided insights into educational policy or suggested policies that should be followed were reported. Of these, ten were articles published in refereed journals, and four were dissertation studies, and one was a technical report..

Learning from the Past

One of the two attempts to learn from the past was by **Klopfer and Champagne** who examined the nation's response to a previous perceived crisis in science education. The authors argued convincingly that the response to the last crisis in science education during the period from 1956-1973 began with the primary control being in the hands of Professionalists—those who saw the goals of science eduction in terms of providing preparation for advanced science study and ultimately professional careers in the natural and applied sciences. The evidence that supported this claim was found in a number of policy documents and in the analysis of the initial national curriculum projects such as PSSC physics, CBA and CHEMS chemistry, BSCS biology, and the AAAS/SAPA, SCIS and ESS elementary school programs. The projects initiated in 1964 and afterwards were found to reflect quite a different view of the goals of science education than those of the Professionalists. The Visionaries who conducted these later projects claimed that the goals of science education were to provide all students the educational background necessary to function in and contribute to a modern technological society. This later group thus emphasized the importance of scientific literacy. Project Physics, A Man Made World, the Intermediate Science Curriculum Study project, Individualized Science and programs to meet the needs of students with specific disabilities were consistent with this broader goal. The authors also noted the limited attention given to middle school programs especially during the first phase of the last reform and the more limited sustained support provided for the second phase projects. Among the authors conclusions were several recommendations for future actions derived from past events. The first was that if the goal of science education is the preparation of all students to meet their responsibilities as citizens, then the professionalists cannot have the primary responsibility for reforms. The second was that national level reforms are unlikely "to survive intact in the ecology of the American educational system" (p. 152). Another was that we cannot expect to develop effective science education programs that build cumulatively on students experiences by beginning with a collection of courses developed at the high school level.

Another study by **Shymansky, Hedges, Woodworth and Berg** provided what is perhaps the most important curriculum study reported in the period covered by this review. Their project was a re-synthesis of the research on student performance in new science curricula, which was originally done in 1983. The re-analysis was completed using substantially improved statistical techniques and a more rigorous selection of the studies included in the meta-analysis. The new analysis accounted for two types of problems, one conceptual, one statistical. The conceptual problem was that the initial analysis did not account for differences in the precision with which the the treatment effects were estimated. The statistical problem was that the initial analysis involved "very serious violations of the assumptions of statistical procedures such as t-tests, analysis of variance, and correlational analysis" (p. 129). The new procedures accounted for these difficulties and provided a more accurate insight into the effects of the new programs.

The results were similar to those reported in the initial analysis in that the science programs developed during the 1960s and 1970s were still judged to have been generally more effective than traditional programs "in improving student performance on cognitive measures and raising attitudes about science" (p. 142). However, there were some important differences that emerged from the new analysis. The primary difference was that the initial analysis found significant differences in seven criterion clusters (composite, achievement, perceptions, process skills, problem solving, related skills and other performance areas), whereas, the re-analysis is indicated that performance was significantly positive in five clusters (composite, achievement, process skills, problem solving and attitudes). Other noteworthy findings were: (a) positive results for achievement and process at the primary level (K–3), attitude and process at the intermediate level (4–6), achievement, perceptions, and process skills, at the junior high (7–9), and achievement and process skills at the high school (10–12); (b) positive effects for new biology and physics programs but not for the new chemistry programs; (c) greater positive effects for students in urban as opposed to suburban and rural settings; (d) positive effects on males but not females, and (e) positive effects attributable to teacher inservice.

Learning from the Present

A second response to the perceived crisis in science education was the attempt to develop greater insight into the existing problems by examining the present system. A very diverse set of nine such studies were reported including two studies of objectives as indicators of educational quality, two statewide status studies of science instruction, one study of student achievement, one study of factors influencing enrollments, one study of typical instructional practices in college chemistry, one assessment of the performance of transfer students from community colleges, and one comparison of the effects of half-year vs. whole year courses.

Two attempts were made to consider objectives as indicators of the quality of school or state curriculum guidelines. **Blood and Zalewski** studied the types of science objectives written by teachers as an indicator of the scope and quality of the science education program in five schools. The objectives were considered to be indicators of program quality on the assumption that "once the intended curricular objectives are written for higher levels, classroom activities will require students to participate in doing science by collecting information for analysis and synthesis." Objectives from five districts at grade levels 3, 6, 8, and 11 were analyzed in terms of their membership in the categories described in Bloom's taxonomy. The results indicated that more than two objectives were written at the low levels for every one written at the higher levels. The conclusion was actually a telling question: "If teachers do not address higher level objectives during curriculum development, then how and when can we ever expect these objectives to appear in the instructional process?" (p. 619)

In the second study, **Coleman** determined science teachers and science educators perceptions of Missouri Key Skills (MKS) and the congruence of those objectives with the Project Synthesis goal clusters. One hundred and ninety-eight teachers and 15 science educators responded. Both groups perceived Societal Issues to be the most important goal cluster. However, eighth grade teachers were more concerned with Personal Needs and tenth grade teachers were more concerned with Academic preparation. The comparison of the Missouri Key Skills to the Project Synthesis goal clusters revealed that the MKS document does not reflect a balanced curriculum.

The third study was reported by **Lawrenz**. She surveyed 7th and 8th grade science teachers to determine their use of instructional techniques compatible with the development of higher-order thinking skills of their students. The sample consisted of 139 teachers who returned a questionnaire that asked teachers to indicate their attitude toward 14 instructional situations and to rate the emphases they gave to 16 objectives, 8 assessment techniques, and 16 types of assessment questions. The teachers reported a belief in laboratory-based, hands-on classes and that all students can learn science. In addition, they reported that students should keep laboratory notebooks, design and conduct their own experiments, and be taught on the higher levels of Bloom's taxonomy. However, the commitment to hands-on, inquiry learning was not completely consistent with the emphasis the placed on various objectives The most emphasized objectives were to learn basic science concepts, become aware of the importance of science in daily life and develop curiosity about natural phenomena. The commitment to hands- on inquiry also was not consistent with the the types of assessment they emphasized. The most common assessment categories was classroom tests followed by homework. The types of questions used most frequently required knowledge of definitions of concepts, the recall of specific information, explaining concepts in their own words, and solving problems with one specific answer. The results of factor analyses and canonical correlations between the factors indicated that although relationships do exist, the science teachers are diverse and individualistic in their reported teaching technique preferences.

A fourth study that took a closer look at the current state of affairs was conducted by **Morey**. The purpose of the study was to determine the status of science education in Illinois elementary schools. The authors argued that while numerous national studies indicate that science education in the elementary schools is inadequate, statewide surveys are needed to provide the specific information needed by state agencies. The specific questions were related to the types of instructional programs, teacher preparation, inservice, obstacles to science teaching, the level of community and business support, and the types of assessment methods used. The sample consisted of 420 randomly selected teachers of which 264 (59%) returned the questionnaire. The results mirrored those found in national studies. A large majority of the respondents reported that they used textbooks alone or in combination with other materials as the dominant type of program and only 12% of the teachers reported using a kits-only approach. The primary science activity reported was the teacher directed discussion. The average of hours of collegiate science course work was 11.2 hours in contrast to the results of another study which reported that effective elementary science teachers had completed 48 hours of science. Their initial background was supplemented by inservice of some type which was available for 40% of the respondents within the past three years. The major obstacles were lack of time, money, equipment, and preparation, with more than half reporting that they lacked the materials and time necessary to teach science. Less than one third of the teachers perceived science as a major priority in their community. Parent participation was reported as very limited, and 60% reported business and industry as never involved. Only 16% of the teachers reported science as their most f vored subject to teach which ranked third behind reading and mathematics. Regarding assessment, the teachers reported limited district wide assessment and the use of teacher observation and teacher made tests as the method that was employed. In conclusion, the author commented on the representative nature of the Illinois populations, compared the Illinois results to those available from other states, and indicated that while the generalizability of the Illinois results should not be taken for granted, there is is little reason to anticipate substantial differences in other states. The conclusions also indicated that the results provide information that is essential for making policy decisions regarding each of the questions that were asked.

Morey's point about the potential importance of statewide studies is evidenced by another study in Illinois by **Gartner** who determined the pattern of science knowledge and skills in Illinois for the years 1977-84. Contrary to many reports, he found that the science performance of students in grades 4 and 11 as measured by Illinois questions of Educational Progress (IIEP) had not declined. The only decline was in the science skills of grade eight students. The author concluded that the data could be used to locate specific areas of science education and grades that require improvement.

Blondeau attempted to examine Arizona physics classrooms in 1988-89 to determine, in part, what factors influenced enrollment. Positive factors appeared to be the number of sections taught by an individual, the past trend of physics growth in the school, the percentage of girls enrolled, the number of college physics credits of the teacher, the advice of peers, and the number of levels of physics offered. A negative factor appears to have been the number of mathematics courses taken by the instructor. One of the most effective ways of enhancing enrollment was educating the guidance counselor about the courses.

Florida State Board of Community Colleges conducted a statewide study to examine issues which affected the teaching of science in Florida's community college and make recommendations to improve the teaching of science in the community colleges. The study involved reviews of existing data, site hearings, and the collection of survey data. Among a variety of findings were the following: (a) 48% of the high school graduates entering community colleges do not have the minimum level of math skills judged necessary for college entry; (b) community college transfer students account for 30% of the enrollment in upper division science programs in the Florida State University System, a much larger proportion than predicted; (c) community college transfer students earn lower grades in upper division science courses than their counterparts who began their post-secondary education in a state university (e.g., 27% versus 52% with GPAs above 3.0 in the life sciences); (d) three out of every four community college transfer students who were interviewed said the university demanded more academically, and (e) on the average, 16% of the general education credits required for a two-year degree from a community college are in science, but only 5 of the 28 community colleges require a science *laboratory* course. Based on these and other findings, the Board made twelve recommendations for further studies or specific improvements.

Johnson studied how undergraduate organic chemistry is currently taught in 33 well-known colleges and universities. On site visits were made to each institutions, faculty members were interviewed, 19 classes sessions were observed, and syllabi, old examinations and problem sets were collected. Most faculty indicated that they follow the textbook sequence of chapters (10 different texts were in use), with the frequent exception of the spectroscopy topics. Real-world applications of organic chemistry receives little attention: about one-half of the faculty wait until the end of the semester to present a few lectures on appealing topics, about one-third incorporate a few full lectures periodically, and one-third pause during a lecture to include a brief dissertation on a special topic. Most of the courses reviewed included a laboratory as a required part of the course. Most laboratories did not use or show UV or mass spectroscopy, and only nine institutions provided hands-on experience with NMR spectroscopy. Infrared spectroscopy was in widespread use, with 24 institutions providing hands-on use. Faculty indicated that they want to see the lab become more realistic as to how organic chemistry is done today, and that means the incorporation of more sophisticated instrumentation and the provision of more hands-on opportunities. Use of video for experimental technique demonstration, instrument usage instruction, or for instructing on the theory of various spectroscopies is uncommon. Computers are almost totally absent from the organic laboratory course. This study suggests that a substantial upgrading of instructional practices in organic chemistry are warranted.

Finally, in British Columbia there has been substantial debated regarding whether full-credit semester or year long course time tables are better with respect to students' science attitudes and achievement (**Bateson**). The debate has been based in part on teachers reports that the full-credit semester system is more effective. Multiple matrix sampling procedures were used to test all grade 10 students in British Columbia on cognitive items from six domains, process skills, knowledge and understanding, application of science concepts, rational and critical thinking, the nature of science, and safety. The items used in the assessment of the cognitive domain were selected to match a table of specifications for the secondary science curriculum. In addition, students reported background information, and were assessed regarding their attitudes toward science as a school subject, science in society, careers in science, and selected specific issues. The results indicated that there were no significant differences regarding students attitudes on any of the scales and significant differences favoring the all-year course timetable for all of the cognitive scales. The differences clearly supported the position that the all-year course timetable was more effective in contrast to earlier studies of the students and teachers perceptions that the full-credit semester course arrangement was more beneficial.

Predicting Best or Likely Actions

A third response to criticisms of science education was to attempt to predict what actions are most likely to substantially improve or change the field. There were two published research papers. One was a cost-effectiveness analysis of possible instructional interventions in science education. The other was a Delphi study of the future of biology courses.

The first of these studies is especially important because decisions are made each day at local, state and national levels, often without the utilization of the full benefits that can be derived from research. One reason for this may be that there are few ways of considering the multiple kinds of information that are available in any coordinated fashion. **Anderson** tackled this problem by applying the principles of cost-effectiveness analysis. Cost effectiveness analysis is an analytic procedure that is designed to help identify preferred choices among a set of alternatives. More specifically, the intent is to show how a given level of benefit can be achieved at some given level of cost. The steps used in the investigation were: (a) the definition of objectives via the analysis of commission and committee reports, (b) the identification of alternative actions by the of the professional and popular literature, (c) the selection of effectiveness measures and the development of cost estimates by analysis of the research literature and estimation where necessary, (d) the selection of decision criteria and (e) the development of models that relate cost to effectiveness

The objectives that were used related to increasing the quantity of time students spend learning science, increasing the quality of the instruction and obtaining an appropriate match between the actual classroom objectives and recommended objectives. A large number of interventions were considered within eleven categories such as increasing student requirements, improving preservice and inservice education, increasing equipment and materials, improving curricula, changing testing programs and developing local leadership. The analysis procedure began with the evaluation of the cost-effectiveness of single types of innovations and then combinations of innovations. The results are reported as matrices that present the relative effectiveness of interventions (high, medium or low) and the relative costs of the interventions (high, medium or low) and the objective with which each intervention would be associated.

The conclusions indicated that increasing the amount of class time used for instruction and increasing productive homework were probably the most cost effective ways of increasing student requirements. Changing preservice teacher education programs is recommended as a cost effective innovation, but it requires a long time for any impact to develop. Inservice teacher education is recommended as effective only if it is part of a broader implementation. Improving school curricula were all relatively low cost, but no interventions in this category were highly effective. A moderately effective innovation was the development of improved school curricula. However, mechanisms for the implementation of the curricula were considered to be essential. Finally, two interventions that would facilitate change were recommended. One was the development of local leadership and the other was the development of testing programs that reflected the goals of new curricula.

There was one study that provided some evidence that there has been a response to the crisis related to the class time students spend in science courses. **Glass** examined enrollment trends in Iowa and reported encouraging results. State department of education data from the period 1978-79 through 1988-89 provided a perspective on the five years before and after the 1983 Nation at Risk report. The data, science enrollments as a percentage of total school enrollments, show modest increases in science enrollments before 1983 (approximately 63% to 66%) and sharp increases from 66% in 1983 to 78% in 1987-88. The data also show that the primary increases have been in enrollments in physics and chemistry. The Iowa data is particularly interesting in that it reflects a state that "relies on citizen input to make decisions concerning the nature of local educational requirements" (p. 247). The author concludes that the results provide some hope that Americans can and are responding to the crisis in science education.

Schofield assessed the impact of biotechnology on undergraduate biology education through 2003. A three-round Delphi instrument was used by a panel of experts, which included leading bio-educators and noted biologists in the forefront of biotechnology, to form a consensus on changes that might occur in the biology undergraduate curriculum. The panel predicted an increased emphasis on molecular biology and genetics and a decline in the study of organismic biology and ecology, although ecology is expected to rebound in the middle to far future. Increased use of instrumentation at all levels, increased emphasis on computer modeling, writing and communication skills, and increased use of problem-based learning are all anticipated. In addition, increased pressure for early specialization is considered likely through 2003. Early research training and increased vocational training are also considered likely, although the latter was considered undesirable. The new technology is expected to continue to raise questions and pose new ethical issues. The use of specific kinds of live material in teaching is expected to be limited, and the inclusion of a Bio-ethics course in the curriculum is considered likely by 2003. The number of biology majors is expected to remain stable or decline.

Reviewer Comments

The results of these studies illustrate how research can inform policy decisions in science education. The studies of past practices provide insight regarding who influences educational policies, indicate that previous curriculum development efforts had substantial effects, and encourage the initiation of new curriculum development efforts. Studies of present practices indicate that carefully developed goals for science education should be used in the development of specific objectives and other specific problems that should be addressed as matters of policy. Finally, the study of both past and present practices was demonstrated as providing a basis for the prediction of future cost-effective actions and probable changes in science curriculum.

There were 14 papers included in this section. Of these, four were journal articles, and ten were dissertations. The papers were divided into those that were descriptive of science education and those that compared science education in two or more countries. There were eleven descriptive papers and three comparative ones. Seven of the eleven descriptive papers used survey techniques to obtain status information and subsequently conducted correlational analyses. Two of these seven supplemented the survey with interviews, and one supplemented the survey with an analysis of science textbooks. Three of the studies presented and discussed the use of theoretical models, and the remaining one was a case study. The three comparative papers included one comparison of student outcome scores, a comparison of curriculum documents supplemented by a questionnaire, and a more theoretical piece which raised and discussed several hypotheses. The comparative papers will be summarized first.

Comparisons Among Countries

Ferko compared United States student achievement in science to achievement in several other countries using the study of Advanced Science Student Achievement of the Second International Science Study. There were several findings and comparisons. Some findings include that each United States advanced science subgroup (those having taken a second year course in biology, chemistry, or physics) had a mean score below the international mean, and the best predictor for science achievement was the score on the mathematics and word knowledge test (an ability measure).

Lawson(b) discussed a series of hypotheses that could be studied in comparative investigations of science education in the United States and Japan. These hypotheses were raised in conjunction with issues developed at a 1986 conference of Japanese and American science educators.

Y. Lin compared elementary school science curriculum development in the United States and Taiwan, Republic of China, during the period 1957-1988. Categories of comparison included factors influencing goals, objectives, and curricular content, the stated goals of elementary schools, similarities and differences of goals, and objectives and desired changes as perceived by science educators from both countries. All available documents (government reports, curricular materials, research studies, etc.) were examined and synthesized and a survey questionnaire was sent to all United States state science supervisors and to 29 members of the Science Curriculum Improvement Committee of the Ministry of Education.

Descriptive Studies of Science Education

The following eleven descriptive studies provide interesting insights into international science education. **Al-Abdulhadi** described how science teachers in Saudi Arabia perceived the articulation between secondary schools and universities. The study used a survey of 200 secondary science teachers and 160 university science teachers. The teachers did not feel that the programs were presently articulated but both groups had positive attitudes toward improving articulation. Some of the barriers included difficulty in getting together and having separate governance.

Bu-Gahhoos examined the high school biology curriculum in Bahrain. The curricular aims, content, teaching methods, and assessment techniques were considered using questionnaires and interviews of teachers and students. All 34 third grade secondary biology teachers were included and 201 students. Students and teachers were not satisfied with the curriculum, and a number of suggestions for improvements were made.

De Villiers examined the problem of biology teacher renewal in the Transvaal of the Republic of South Africa. The idea of renewal and what promotes it was researched to provide a theoretical framework. Subject matter experts were interviewed and biology teachers were asked to respond to a questionnaire. It was concluded that the biology teachers were not fully aware of the necessity for renewal and that they do not utilize all available opportunities.

Dongol described and evaluated a training program for science teachers in Nepal. The evaluation consisted of three case studies conducted during and after the 150-hour training program. The case studies indicated that the training program can change classroom teaching behaviors from rote memory-oriented to student-centered approaches. It can also develop the understanding of the modern view of science and rationale for science teaching.

Finegold and Tamir examined the relationships among the intended curriculum opportunity to learn and the achieved curriculum for physics in Israel using data from the Second International Study of Science Education (SISS). Students were classified as physics specialists if they were in a twelfth-grade physics class at the time and as science specialists if they were in the twelfth grade taking a general science test. The third group was ninth-graders. The results from the individual group and between groups were compared by item and percent achievement to examine student understanding of various physics concepts. The authors point out general areas of misunderstanding and raise the issue of what should count as satisfactory achievement.

Foukaridis presented a model for the training of baccalaureate degree chemists in the Republic of South Africa using the ideas of competency-based education. The model was used for the identification of content in general, organic, inorganic, physical and analytical chemistry. One suggestion from the model was that in order to best meet the needs of a developing country like South Africa two courses in analytical chemistry may be necessary. Furthermore, the model suggested that the amount of time presently spent on chemistry instruction was not sufficient.

Hill and Tanveer described a systematic plan for implementing a national curriculum development effort in Pakistan. The setting which influenced the design of the six-year cycle included the nature of schooling, the national and regional agencies which guide the education system, the vision and aims of the nation for educational development, and the unique history and culture of the country itself. The six years were divided into three 2-year stages, unfreeze (where conditions are made fluid and open to change), reforming (where new ideas and arrangements are introduced), and refreezing (where the new things are stabilized). Three criteria were offered for developing successful programs elsewhere: systematic planning, involvement of external agencies for review, critique and perspective, and development of a model unique to the country.

Hsu analyzed a model for developing instructional material for teaching physical science concepts for grade 8 students in Taiwan Republic of China. Students were taught with a new curriculum based on the learning cycle of correlation, analysis, and generalization or with the standard curriculum. It was found that students using the new curriculum achieved more. Other correlational findings were also reported.

Huang described the needs, availability, and use of media-aided instruction in upper elementary schools in Taiwan, Republic of China. A survey was sent to teachers, and results were examined by several variables such as gender, age, teaching experience, school location, and attendance of in-service programs. Teachers were shown to be accustomed to scarcity of and unfamiliarity with media materials. Other variables showed relationships with use of media.

MacDonald and Rogan described the factors influencing the introduction of instructional change in Black South African classrooms. The instructional change is part of the Science Education Project involving teachers from about 2000 schools. Five factors were reported as most important: teacher uncertainty, the epistemology of science and science education, the provision of resources, the image of the innovation, and the system. The study revealed the strong effects context has on implementing change in the classroom.

Mrazek described a methodology for assessing and enhancing the Canadian context in science education. The study proceeds though a four stage development process of a grade 8 geology science program. First, a theoretical framework was developed and validated. Second, model curricular materials were developed. Third, teachers and others were surveyed and interviewed as to what they were doing or what might be possible. Fourth, a synthesis was conducted. Finally, the four stage development procedure was reviewed and refined.

Reviewer Comments

The studies in this section provide a diverse look at science education in institutional settings. The descriptive and comparative studies provide a rich data base for future work. As we become a more international community, studies like these will become more important. We have a lot to learn from each other, and studies like these provide a forum to begin the learning process. Future studies should concentrate more on finding generally applicable information and on addressing the issues involved in making appropriate international comparisons.

Uses of Technolcgy

There were 17 papers that dealt with the use of technology. Of these, one was a presentation, one was a research report, four were journal articles, and eleven were dissertations. Thirteen of the papers compared one type of technology-oriented treatment to some other situation. These studies used quasi experimental, pre-post testing designs and a variety of instruments to measure various effects. Often the treatment effect was crossed with other factors such as gender or group size. The remaining four studies used a variety of designs. One compared achievement with pre-specified objectives; one was a correlational study of different variables; one analyzed key stroke input in conjunction with in-depth interviews; and one was an ethnographic study of a classroom.

Comparisons Among Treatments

In this set there were nine comparisons of technology-oriented instruction with traditional instructional methods, three examinations of the effect of computer or learner control over the learning sequence in computer-assisted instruction, and one investigation of the effects of different timing of computer-based practice after instruction.

There were three studies that compared microcomputer-based laboratories (MBL) with traditional instruction. **Adams and Shrum** examined the effects of MBL exercises on the acquisition of line graph construction and interpretation skills by high school biology students. Twenty students from each end of the ability continuum in graphing assessment were put in experimental and conventional groups. There were no interactions between ability and instructional method. Students taught by the conventional method outperformed the experimental students in graph construction. There were no differences for graph interpretation.

In a second study, **Chin** examined the effectiveness of microcomputer-based laboratories on teaching scientific skills and concepts to seventh graders. Students were put into either traditional or MBL groups. The main difference in the two groups was the use of computers to construct graphics. The MBL group had higher post-test scores, and the MBL appeared to work equally well for students of different ability levels.

The real-time nature of microcomputer-based labs have been shown in previous research to account for the improvement in student achievement. **Belchner** attempted to determine if the simultaneity of perception of an event and its graph is the important real-time variable. If so, then a video recreation of a motion event alongside its graph should also be superior to traditional kinematics laboratory instruction. VideoGraph students did not have significantly higher scores on a kinematics posttest than traditional students. The authors suggest that it may be the students ability to control the motion—make changes and see its effect, rather than the visual juxtaposition of event images and graphs, that accounts for the superiority of microcomputer-based kinematics labs.

There were two studies that compared simulation laboratories with traditional laboratories. **Kruse** investigated the effects of laboratory investigations using interactive videodisc or computer simulations on college student outcomes. There were no differences for controlling for variables, number of measurements made, and success in finding a relationship between variables being studied. Students using either type of simulation spent less time on task than students using traditional methods and interacted less with the supervisor. Students felt the videodisc simulation was more realistic than the computer simulation.

A similar result was obtained in a second study by **Crawford**, who investigated student achievement, time on task, and attitude toward microcomputer instruction in relation to the Meyers-Briggs psychological subgroup types (IN, EN, IS, and ES) using college students in a genetics class. The 52 students in the control group received a conventional lecture discussion and laboratory approach to a unit on Mendelian genetics while the 39 experimental group students covered the same topics but with microcomputers to simulate fruit fly crosses. No differences were found for psychological subgroups, instructional method, or time on task.

However, the addition of computer simulations to a traditional curriculum was found to be effective in one study. **Faryniarz** investigated the effect of microcomputer simulations on the process skills of community college students. The simulations addressed lake pollution analysis, waste water quality management, and population dynamics. The experimental group watched the simulation while the control group did not. The process skill test showed significant improvement in problem solving for the experimental group.

There were three other studies that compared technology-oriented instruction with traditional instruction. **Ebert-Zawasky** investigated the use of computer-interfaced videodisc systems into the teaching of introductory biology at the college level. Sixty-six students were divided into three sections, two experimental and one control. All groups watched videodisc presentations on the same topics. The experimental students were put into small groups, and each group designed a presentation on an assigned topic. Then the students viewed each others, presentations. The control group students viewed presentations prepared by the instructor. Several independent variables were included in the study as well. No significant effects were found. Students in the experimental groups were able to learn how to make videodisc presentations, however, and seemed to enjoy the experience.

Gardner, Simons, and Simpson investigated the effect of computer-assisted instruction and hands-on activities on elementary students' attitudes and weather knowledge. Three treatments were contrasted, hands-on alone (I), hands-on and the weather school software (II), and a more text-based approach (III). There were 47 students in treatment I, 46 in treatment II and 21 in treatment III; all from five third grade classrooms. Treatment II was found to be superior to treatment I and treatments I and II were both superior to treatment III.

Jegede, Okebukola, and Ajewole investigated the effect of cooperative learning and computer use on learning of biological concepts and attitude among 64 students in Nigeria. Favorable results were shown for cooperative groups, for interactive use of the computer, and for girls in the computer-assisted group.

There were three papers that reported investigations of user control variables. **El-Sanhurry** investigated the effect of computer or learner control on 116 junior high school students classified as formal and non-formal reasoners. Achievement and attitude were measured before, after, and one month after the treatment. Students who controlled the learning sequence spent less time on task but there were no differences in achievement. No significant differences were found.

A similar result was obtained in a study by **Doherty**, who investigated the effects on learning of three different patterns for the presentation of computer-assisted drill problems. College students practiced labeling and pattern recognition tasks in a computer-based tutorial on molecular structure in one of three task-sequencing treatmen' . (1) a fixed series of random problems, (2) a sequence entirely user-selected, and (3) a sequence programmed for mastery learning. There were no significant main effects for treatment and no significant interactions.

However, a third study found a user-control effect. **Bill** examined the effect of learner and computer controlled conditions in a computer-assisted instruction environment with veterinary students for learning pharmacokinetic concepts and attitudes. Other variables were advance organizers and student locus of control. When allowed to choose, learners spent less time on task and scored significantly lower than those students controlled by the computer. This result was true regardless of organizer or locus of control.

Juang investigated the effects of different timing of computer-based practice after instruction on students' problem-solving performance. The subjects were 276 eighth grade students in Taiwan. Some students practiced immediately, some delayed one day, and some delayed two days. There were no differences among the treatment groups and no interactions with five independent variables: gender, mathematical ability, field dependence/independence, prior computer experience, and attitudes toward science.

Additional Studies

The remaining four studies in this group were descriptive or correlational in their examination of the use of technology. **Barak** investigated the effect of a modular learning unit covering the study of basic principles of computerized feedback control using light intensity. The program was tried out with 137 secondary students and 40 college students. After completing the unit, the students completed an achievement test, an individual practical performance test, and a questionnaire or a forecast. It was determined that the students had achieved the objectives of the unit.

Barber investigated the influence of learning modality preference and personality factors on learning strategies and outcomes in an autotutorial course in veterinary medicine. There were six variable sets with a total of 18 variables plus demographics. There were 70 students. Seven findings were reported: (a) the individual characteristics, modality preference, and personality factors of students do not affect achievement or attitude. (b) differences in learning aid use and study strategy of students do not affect achievement or attitude. (c) personality characteristics of students affect learning aid use and study strategy. (d) personality characteristics and modality preference of students are interrelated. (e) no relationship exists between student achievement and attitude. (f) achievement is negatively correlated with age. and (g) females are more open to new experiences than are males.

Flick(b) investigated the interaction of intuitive physics with computer-simulated physics by analyzing the keystroke input of 19 sixth grade students using Logo turtle graphics to simulate a frictionless object. Ten students (5 boys and 5 girls) were interviewed concerning perceived relationship between keyboard input and turtle behavior. Subjects who could clearly state some keyboard effects did not score high on either computer analysis yet achieved the most general solutions of the computer problem. They explored the tu.tle behavior under a greater variety of conditions than subjects who achieved partial solutions.

Kim conducted an ethnographic study of an eighth grade science classroom over 16 months. As the teacher used MBL, his role moved from that of a knowledge provider to one of a partner. Student process and product was presented by three themes: student interest, sense of self esteem, and peer collaboration.

Five other studies involving computers were reviewed elsewhere in this document. **Donn** was reviewed in the Conceptual Change and Achievement section, **Berge** and **Friedler, Nachmias and Linn** were reviewed in the Science Process/Inquiry Skills section, **Slick** was reviewed in the Problem Solving section, and **Klevans** was reviewed in the Informal Science Centers section.

Reviewer Comments

The research described in this section is consistent with the level of technology in science education. Technology in science education is an emerging field, and the research reviewed here is of the straightforward, preliminary nature characteristic of a new field. The studies rely heavily on pre-post testing of a few variables using comparison groups in short-term interventions. Future studies should concentrate more on, the synthesis of existing knowledge, the expansion of the variables, and contexts studied and the development of instructional theory.

Analysis of Science Textbooks

Since textbooks play a major role in science education, a description of the nature of textbooks and how students learn from texts is an important area of research. In 1990 there were nine studies in this area, seven articles in refereed journals, and two dissertation studies. Six studies employed a wide variety of criteria for analyzing and describing the inadequacies of science textbooks. The remaining three investigations, which were based on theories of information processing, dealt with the comprehension of science textbooks; two of these used different techniques to analyze the reading difficulty of textbooks, and one study reported the characteristics of comprehension monitoring by students.

Inadequacies of Science Textbooks

There were a wide range of studies that dealt with the adequacy of science textbooks. In general, two types of analyses of texts were conducted. Two papers reported analyses of the prose or diagrams in textbooks which could lead to student misconceptions. The remaining four papers dealt with the extent to which current goals or modern perspectives of a particular discipline are reflected in secondary or college textbooks.

Misconceptions

Children's personal understanding of concepts may be enhanced or confounded by the textbooks they use. The purpose of a study by **Barrow** was to determine which of eight magnet concepts are found in ten elementary school science textbook series, how the concepts were presented (prose, illustration, or laboratory activities), and to identify potential magnet misconceptions. The author found that magnet concepts are found at least once in textbooks series for grades 1-3 and 4-6, the eight magnet concepts were addressed in all series except one, and most concepts were introduced through prose (except for the uses and types of magnets). Some textbooks identify that the poles are located at the ends of magnets. The author commented that this could promote a misconception because children's' home experiences are usually with ceramic magnets that have poles located on surfaces.

Wheeler and Hill analyzed several diagrams presented in textbooks from the perspective of how they may unintentionally contribute to students' misconceptions. For example, diagrams of the molecular arrangement of solids, liquids and gases usually over-represent the increase in spacing between particles when depicting the change from solid to liquid. This could lead to the misconception that liquids are far more compressible than is the case. Similarly, diagrams usually exaggerate the expansion of a solid when heated. When high school seniors were asked to select from several diagrams showing the expansion of a copper bar, half of the students choose one of the exaggerated diagrams consistent with the diagrams in their text. Difficulties in interpretation arise because students are unaware of the conventions for using different types of diagrams (pictorial/realistic, semi-pictorial, or abstract) for different educational purposes (to describe/report, summarize/generalize or explain/model). The authors presented a framework to help students distinguish between the intended purpose of a diagram and the represented form of a diagram.

Treatment of Modern Perspectives

S. H. Lin analyzed the earth science textbook used in the junior high schools in Taiwan in terms of new goals for science education related to the nature of science, the interrelationship of science, technology and society, openness of laboratory activities, and type of questioning style. The results indicated that less than 1.3% of the narrative page space is devoted to the nature of science. In particular, the tentativeness of science is rarely presented. Less than 17.1% of the narrative page space is devoted to the interrelationship of science, technology and society (STS). The passages related to STS are most often associated with topics of environmental quality and national resources. Most of the laboratory activities provide the problem, the procedures, and the desired result prior to the experience. Similarly, most of the questions are low-level recall, and the tests focus on information requiring vocabulary and facts. When this textbook was compared with a similar earth science text used in the U.S., no significant differences were found. The author concluded that neither textbook is adequate to assist students in reaching the current goals for science education.

Borger evaluated the environmental content of science and geography textbooks the published curriculum guidelines for grades 7–12 for the Ontario schools. The author also investigated whether the environmental content was presented from an "Environmental Perspective" based on a 20-year analysis of data and issues. Both qualitative and quantitative approaches were used. The results indicated that only a small amount of environmental content was present in the secondary curriculum and this content was not presented from the "Environmental Perspective." The author concluded that the textbooks and published curriculum guidelines are negligent in their treatment of environmental issues.

Studies of high school biology textbooks have indicated a marked decrease in emphasis on evolution in these textbooks since the 1960's. **Glenn** examined high school earth science textbooks to determine whether or not there is a similar trend in earth science texts. The authors examined the 1960 - 1989 editions of three textbooks; two frequently used textbooks in secondary schools (7 editions of each), and one based on the original Earth Science Curriculum Project (4 editions). All texts published from the late 1970s through the early 1980s carry a statement that any references to evolution are presented as theory rather than verified fact. This statement does not appear in the one text edition published in 1989. All three texts provide descriptions of the history of life on earth which clearly show the progression of life from simple to complex during the course of geologic time. However, the texts provide less space in the 1980s editions to the history of life than they did in the 1960s. In the two traditional texts, the pattern is to use words like "appeared," "thrived," "progressed," and "gave rise to" when describing changing life forms. The mention of Darwin's name and the use of the words "evolution,"or "evolved" are uncommon. All three texts de-emphasize the origin and evolution of man; some editions do not mention early man at all, while in others he merely appears in the Pleistocene without additional elaboration. The Earth Science Curriculum Project text still provides the most complete coverage of evolution. The author concluded that the traditional lack of emphasis on evolution has not changed much in the two traditional textbooks.

The geological sciences are steadily becoming more mathematical and quantitative and more strongly based in physics and chemistry. To see if this change is reflected in current textbooks, **Shea** analyzed the mathematics and chemistry content of 15 college-level physical geology textbooks published between 1980 - 1990. He found that mathematical equations are seldom used as an integral part of the subject (0 to 20 equations), very few worked examples are provided as learning aids (0 to 7), very few of the end-of-chapter questions call for use of the given equations (0 to 4), virtually all of the mathematics used is at the college-algebra level, the use of constants is mostly avoided, and high-school level stoichiometry is nonexistent. Further, the college-level texts have significantly less mathematics than even the 1967 Earth Science Curriculum Project 9th-grade text. The author suggested that the non-mathematical character of the introductory textbooks gives an erroneous picture of geology as a purely descriptive and historical science.

Reviewer Comments

The first two studies suggest that additional research is needed in instructional strategies that help students comprehend both the prose and the diagrams in science textbooks. The remaining studies are useful in documenting the inadequacies of our science textbooks. Many science texts appear to be a traditional, encyclopedia-like collection of topics that neither reflect our current goals in science education nor a modern perspective of science.

Comprehension of Science Textbooks

Anderson and Botticelli investigated whether quantitative techniques to measure the information organization of texts matches the subjective evaluation of published book reviewers. They analyzed four introductory biology texts, one that was judged to easy to read and suitable for 9th or 10th grade, two that were intermediate in difficulty and judged to be suitable for average students in high school, and one text judged to be more difficult and suitable for advanced high school or college students. Two different coding schemes were used to calculate a "progression density coefficient" for each text. The coefficient reflects the extent to which linkage words are present in the text that can provide contextual cues for the reader, and the rate at which new words are introduced in the text. The higher the coefficient, the greater the cognitive demand of the text for the reader. The explicit-coding method for calculating the coefficient is based determining the proportion of unmatched words in consecutive sentences. The implicit-coding method is based on an analysis of the major biological conceptual categories of the parts of speech (e.g., molecular, cellular, organism for nouns) in consecutive sentences. Analysis of variance indicated significant differences in the explicit-coding coefficients for the four texts. The increasing values in the coefficient across the four texts corresponded to the increasing difficulty of the texts as rated by reviewers. There were no significant differences in the implicit-coding coefficients for the four texts. This indicates that the four texts have very similar implicit themes (e.g., molecular structure, organismic structure) and levels of organization. The authors concluded that the quantitative methods of content analysis used in the study may be a useful addition to classical methods of assessing reading difficulty of textual material. Further research is needed to determine how different values of the coefficients are related to text comprehension by students with different reading capacities and to students' perceived satisfaction with the text.

Lloyd analyzed how three biology textbooks elaborate the content related to photosynthesis. Elaboration is the embellishment of ideas through the inclusion of relevant details or background information, analogies, or examples. Elaboration affects reading comprehension because it can enhance students' memory of the presented information and can add to the meaningfulness of an idea by making concepts relevant or non-arbitrary. The three textbooks selected for the study are designed for different student populations. Textbook I is intended for non-college-bound students with average ability and below-grade-level success. Textbook II is intended for students with average ability and low achievement who are identified as special education students. Textbook III is written for high school students at all levels. A concept analysis identified four major photosynthesis concepts across the three texts: the requirements, the process, the products, and the by-products. These general concepts were evaluated for the nature and number of elaborations. The results indicated a lack of depth of coverage of any of the major concepts of photosynthesis by Textbook I. Both Textbook II and III elaborate on many of the major concepts, but to different degrees. For example, Textbook III develops the concept of chlorophyll through 19 related ideas, while Textbook II uses only 9. On the other hand, in the discussion of raw materials required for photosynthesis, Textbook II presents more related information about carbon dioxide, water and minerals than does Textbook III. The author suggested that further research is needed to determine how the different elaborations in these texts affect the learning of different types of readers.

Otero and Campanario investigated the characteristics of comprehension monitoring by secondary school students when reading physical science passages. The sample consisted of 63 12th-grade students and 65 10th-grade students from four intact classes in two public schools in Madrid. Students were presented with a booklet containing six paragraphs of between 74 to 97 words, four of which included an explicit contradiction in the second and last sentences. They were asked to rate the comprehensibility of each paragraph on a 4-point scale, underline the conflicting sentence or sentences if they found any problems understanding each paragraph, and explain the nature of the difficulty. When students turned in this booklet, they received a second booklet that informed students of the contradictory sentences in four of the paragraphs. The students who indicated that they had realized the existence of the contradiction without reporting it were asked to explain their reason for not having done so. These students, as well as students who detected some of the inconsistencies but rated the comprehensibility of the paragraph as good or fairly good, were interviewed at the end of the sessic The responses were categorized as (1) absence of evaluation (contradiction remains undetected), (2) adequate evaluation but inadequate regulation (the contradiction is identified, but the contradictory sentences are not underlined and either not explained or "explained away," (3) adequate evaluation but the difficulty is undervalued (contradiction is identified and explained, but the text's understandability is rated good or fairly good), or (4) adequate detection and rejection. There were significant differences between grade levels in contradiction detection ($M = 1.42$ identified contradictions for 10th-grade and $M = 3.27$ identified contradictions for 12th-grade students), indicating that the students' ability to adequately evaluate their comprehension increases with age. There were also significant differences between the percentages of the contradictions detected which remain undeclared until the second part of the test (30% in grade 10 and 9% in grade 12), indicating that younger students have greater difficulties in the regulation phase of comprehension. The authors suggested that the effectiveness of improved written materials could be severely diminished unless there is an adequate development in science students of comprehension monitoring abilities.

Reviewer Comments

The results of these studies are very promising and warrant continued research in this domain. As two of the the authors noted, additional research is needed to determine how the theory-based measures of text difficulty are related to students' comprehension of the texts. In addition, additional research is needed in instructional strategies that will improve students' comprehension monitoring skills. The first two studies found a remarkable uniformity of implicit content themes and levels of organization of texts intended for different audiences. Anderson and Botticelli noted that there did not appear to be much attention paid to planning the communication of different conceptual meanings for audiences with different cognitive abilities. Recent information processing theory and research suggests that the implicit and highly abstract references to thematic ideas found in current textbooks may not be as productive as the use of clearly stated explicit themes and goals that are used throughout the text to organize and interrelate new information. Additional research is needed to produce and test the effectiveness of text material with explicit conceptual themes that match the age, interests and abilities of students.

Informal Science Centers

There were six studies conducted at informal science centers, five at science museums and one at a zoo. Two studies were presented at professional meetings, three were dissertation studies, and one was published in a refereed journal. Four of the studies employed unobtrusive observations of visitor behaviors, and two used pre- and post-testing of selected visitors. Although the studies are unique and situation specific, there were two broad categories related to the purpose of the studies. Four studies dealt with the effectiveness of an exhibit area or specific exhibit, and two studies reported investigations of specific interventions designed to improve visitors' interaction or learning at exhibits.

Effectiveness of Exhibits or Exhibit Area

Churchman and Bossler investigated visitor behaviors at the Singapore Zoological Gardens. Two types of observations were made. First, 15 visitor groups were observed and followed to determine how the total time spent at the zoo is divided among various activities. The mean total time at the zoo was 155 minutes. Most of this time (67%) was spent watching the shows and viewing the exhibits, followed by other activities such as the tram ride (26%), eating (8%) and shopping (1%). The observation data was also used to determine the route most likely to be followed by a visitor. The other type of observation was conducted at 18 specific exhibits. Visitors were timed for three one-hour periods (10–11:00 AM, 12–1:00 PM, and 2–3:00 PM) at each exhibit. The mean time viewing an exhibit was 63 seconds, but varied considerably among exhibits. There were no significant differences in time spent at an exhibit by visitors of different race or by visitors who approached the exhibit from different directions, but there was a significant difference for time of day the exhibit is visited. For most exhibits, visitors spent more time when the animal was moderately or very active, and less time if the animal was inactive or asleep. The authors concluded that the observation methods employed in the study provide adequate information on several variables of interest to zoo professionals.

The purposes of a study by **Eratuuli and Sneider** were to determine: (a) who visits the Wizard's Lab (physics discovery room) at the Lawrence Hall of Science; (b) whether the goals of the Wizard's Lab were achieved by most visitors; and (c) how visitor behavior relates to their understanding and enjoyment of the exhibits. The goals of the Wizard's Lab are to have visitors enjoy performing the experiments, participate in the hands-on activities, and increase their understanding of science by observing and experimenting with phenomena. Two instruments were developed: a questionnaire was filled out by 120 subjects, and an observation form used to collect data on 236 subjects. Sixty-six percent of the visitors were children aged 4 - 18, and most visitors (94%) came with someone else. Analysis of the observation data indicated that the goals of the Wizard's Lab were achieved by the majority of visitors. Ninety-two percent of the visitors enjoyed interaction with the exhibits, 82% were observed to handle the equipment appropriately, 71% appeared to make correct observations, and 65% seemed to understand the meaning of the experiment. A principal components analysis of the observation data indicated that there were three general approaches of visitors to the exhibits: systematic seeking after meaning (34% of the variance), working as part of a team (21% of the variance), and inventing new ways to use the material (9% of the variance). The variable "visitor enjoys performing experiment" loaded on all three factors, indicating that there are alternative ways to enjoy an experiment.

DeMouthe observed visitor behaviors at a museum to determine the characteristics of the most educationally effective exhibits. Effective exhibits were defined as those that attract and hold visitors attention and prompt the most positive behaviors, interactions, and gestures. The correlational results indicated that of the six subject areas investigated in the study, zoology, geology and botany prompt the most positive visitor reactions. Static displays that include natural objects were found to be the most educationally effective. Exhibits that consist of text and graphics, but contain no objects, are the least effective. Although movement is an attractive component to an exhibit, it does not necessarily ensure appreciation of the display.

Klevans evaluated the effectiveness of a computer exhibit in improving (a) the learning of elementary students in grades 1–3, and (b) the beliefs of adult and college populations. The exhibit, "Vanishing Species of Texas," utilizes a Macintosh SE20 and HyperCard software to present information about endangered and threatened species through animated scenarios and informational databases. Changes in elementary students' achievement was measured by a 14-item test which required the identification of pictured species as extinct, endangered or neither extinct nor endangered. Students on school trips completed the test prior to and following interaction with the exhibit. An 11-item, Likert-type questionnaire was used to measure changes in beliefs about endangered and threatened species. College students and adults were polled prior to and following the opening of the exhibit. The results indicated a significant gain in achievement scores by the elementary students and a significant increase in positive beliefs by the adults and college students.

Specific Interventions

Cañizales de Andrade investigated whether the use of an activity worksheet during class visits to a science exhibit effected students' learning. The sample consisted of 246 2nd and 3rd grade students from five school districts in southwestern Michigan. Classes were randomly assigned to either a structured or a non-structured visit. During structured visits students used an activity worksheet that focused their attention on concepts, displays, and activities presented in the exhibit. During the non-structured visits students interacted with the exhibit according to their own interests. After the visits, students were administered a test to assess achievement of the objectives of the exhibit. Analysis of variance indicated that students who experienced structured visits scored significantly higher than students who experienced non-structured visits. However, there was a significant gender difference in achievement.

Bennett and Thompson investigated whether the presence of an exhibit interpreter is effective in attracting and focusing the attention of casual visitors in science museums. The role of the interpreter is to explain or show how the hands-on, interactive exhibits operate, point out scientific principles illustrated by the exhibit, or complement exhibit information in other ways. Two observations were conducted, one on a weekday and one on the weekend at each of two museums in Virginia. For each observation the subjects were the first 50 visitors to enter the exhibit area when the interpreter was present and was not present. Visitor behavior at each exhibit was filmed unobtrusively by a stationary camera. Analysis of Variance indicated that the presence of an exhibit interpreter significantly increased the time spent and the number of attending behaviors demonstrated in the exhibit area at each museum on the weekdays, but not on the weekends (although the trend was in the predicted direction). Examination of the videotapes indicated that on weekends, visitors are more likely to move in groups in which one of the members acts as an exhibit interpreter.

Reviewer Comments

These studies contribute to our understanding of the characteristics of effective exhibits and the kinds of learning experiences visitors have at informal science centers. Interactive computer exhibits can be effective in improving visitors' knowledge and beliefs. In science discovery rooms, there appear to be different general visitor approaches to exhibits that lead to both enjoyment and understanding. Activity worksheets can increase the learning of children during class visits to a museum, and an exhibit interpreter is an effective attention-focuser at museums. Two of the authors noted that in addition to correlational studies based on observations of visitors, more experimental studies and case studies need to be done. For example, do visitors to discovery rooms *increase* their understanding of science. What do visitors learn from interactions with an exhibit interpreters? What are the relative merits of different interpreter techniques (e.g., interpreter disguised as a casual visitor versus formal presentations by interpreters)?

Note Regarding ERIC Numbers

References identified with an ED number have been abstracted for the Educational Resources Information Center (ERIC) and are in the ERIC database. The database can be accessed online, via CD-ROM, and through the use of paper indices. Most documents having an ED number are available in ERIC microfiche collections at over 1,000 locations worldwide. Documents can also be ordered through the ERIC Document Reproduction Service (EDRS): 1-800-433-ERIC. For more information about the ERIC system, contact ACCESS ERIC (1-800-LET-ERIC). For more information regarding the products and services of the ERIC Clearinghouse for Science, Mathematics, and Environmental Education, contact ERIC/CSMEE, Room 310, 1200 Chambers Road, Columbus, OH 43212.

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